AFRL-RQ-WP-TR-2014-0060

EVALUATION OF FATTY ACID METHYL ESTER (FAME) CONTAMINATION ON THE THERMAL STABILITY CHARACTERISTICS OF MILITARY JET FUELS (JP-8 AND JP-5)

Robert W. Morris Jr.

Fuels and Energy Branch
Turbine Engine Division

James R. Shardo, Ashil K. Higgins, Zachary West, Sam Tanner, and Rhonda Cook

University of Dayton Research Institute

Jennifer Kelley

Universal Technology Corporation

DECEMBER 2013
Interim Report

DISTRIBUTION STATEMENT A: Approved for public release. Distribution is unlimited.

STINFO COPY

AIR FORCE RESEARCH LABORATORY
AEROSPACE SYSTEMS DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7542
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

AFRL-RQ-WP-TR-2014-0060 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

*//Signature//
CHRISTOPHER E. BUNKER
Program Manager
Fuels and Energy Branch
Turbine Engine Division

//Signature//
MIGUEL A. MALDONADO, Chief
Fuels and Energy Branch
Turbine Engine Division

//Signature//
CHARLES W. STEVENS
Lead Engineer
Turbine Engine Division
Aerospace Systems Directorate

*Disseminated copies will show “//Signature//” stamped or typed above the signature blocks.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
December 2013	Interim	01 September 2013 – 01 December 2013

4. TITLE AND SUBTITLE
EVALUATION OF FATTY ACID METHYL ESTER (FAME) CONTAMINATION ON THE THERMAL STABILITY CHARACTERISTICS OF MILITARY JET FUELS (JP-8 AND JP-5)

5a. CONTRACT NUMBER In-house
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER 62203F

6. AUTHOR(S)
Robert W. Morris Jr. (AFRL/RQTF)
James R. Shardo, Ashil K. Higgins, Zachary West, Sam Tanner, and Rhonda Cook (University of Dayton Research Institute)
Jennifer Kelley (Universal Technology Corporation)

5d. PROJECT NUMBER 5330
5e. TASK NUMBER N/A
5f. WORK UNIT NUMBER Q0N9

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Fuels and Energy Branch (AFRL/RQTF)
Turbine Engine Division
Air Force Research Laboratory, Aerospace Systems Directorate
Wright-Patterson Air Force Base, OH 45433-7542
Air Force Materiel Command, United States Air Force

University of Dayton Research Institute

Universal Technology Corporation

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-RQ-WP-TR-2014-0060

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Aerospace Systems Directorate
Wright-Patterson Air Force Base, OH 45433-7542
Air Force Materiel Command
United States Air Force

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/RQTF

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RQ-WP-TR-2014-0060

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES
PA Case Number: 88ABW-2014-0953; Clearance Date: 7 Mar 2014.

The U.S. Government is joint author of this work and has the right to use, modify, reproduce, release, perform, display, or disclose the work.

14. ABSTRACT
A series of Advanced Reduced Scale Fuel System Simulator (ARSFSS) Runs evaluating the impact of Fatty Acid Methyl Esters (FAME) contamination on the thermal stability of a Jet A additized with a military package of additives, a JP-8 and a JP-5, were accomplished. BFA wetted-wall temperature change profiles were obtained and carbon deposition was measured. It is therefore generally concluded that FAME has no significant impact on either Jet A with the military package of additives or JP-8 or JP-5, although the data is less conclusive for the JP-5 than for the Jet A with the military package of additives and the JP-8.

15. SUBJECT TERMS
FAME; JP-5; JP-8; thermal stability; fuel system simulator; fuel contamination

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Christopher E. Bunker
Unclassified	Unclassified	Unclassified	SAR	56	**19b. TELEPHONE NUMBER** *(Include Area Code)* N/A

TABLE OF CONTENTS

List of Figures

List of Tables

Acknowledgements

Special thanks to the following folks who played a critical role in the completion of this work:

Jim Shardo, UDRI, for ARSFSS Operations

Kim Higgins, UDRI, for ARSFSS carbon burn-off and photographs

Sam Tanner and Rhonda Cook, UDRI, for managing the fuels and additives involved in this program

Zach West, UDRI, for Quartz Crystal Microbalance (QCM) work and data interpretation

Jennifer Kelley, UTC for data analysis and plotting

List of Acronyms

ACRONYM LIST	
Acronym	**Definition**
AFPA	Air Force Petroleum Agency's Wright-Patterson Aerospace Fuels Laboratory
AFRL	Air Force Research Laboratory
AFTSTU	Aviation Fuel Thermal Stability Test Unit
ARSFSS	Advanced Reduced Scale Fuel System Simulator
BFA	Burner Feed Arm
EDTST	Extended Duration Thermal Stability Test
FAME	Fatty Acid Methyl Ester
FCOC	Fuel-Cooled-Oil-Cooler
FDV	Flow Divider Valve
GDTC	Generic Durability Test Cycle
HP Pump	High Pressure Pump
JFTOT	Jet Fuel Thermal Oxidation Tester
mg	milligrams
QCM	Quartz Crystal Microbalance
RQTF	Fuels and Energy Branch, AFRL
SV	Servo Valve
WWT	Wetted Wall Temperature

1.0 EXECUTIVE SUMMARY

A series of Advanced Reduced Scale Fuel System Simulator (ARSFSS) Runs evaluating the impact of Fatty Acid Methyl Esters (FAME) contamination on the thermal stability of a Jet A additized with a military package of additives, a JP-8 and a JP-5 were accomplished. BFA wetted-wall temperature change profiles were obtained and carbon deposition was measured. Photographs were taken of deposition on fuel-wetted components.

In all cases, with the exception of JP-5, data shows no significant difference in deposition from a baseline fuel and a FAME-contaminated fuel. For these fuels, it can be concluded that FAME contamination of Jet A used as a replacement for JP-8 and JP-8 itself will not likely adversely impact weapons systems using these fuels, regardless if the exposure to the contaminated fuel is periodic or long-term.

For the JP-5, there is conflicting evidence regarding the impact of FAME on this fuel, primarily due to the malfunction of test hardware. However, even considering the likelihood that the test hardware may have had an impact on the test data, it can be reasonably concluded from an examination of the data that if there is a negative impact of FAME contamination on JP-5, the impact is minimal. Therefore, no adverse impact would be expected on weapons systems using FAME-contaminated JP-5 as long as that exposure to the contaminated JP-5 was minimal or periodic.

These fuels were also evaluated in the QCM. Results of these analyses show that for JP-8 and Jet A plus the mil-pack additives, FAME has no detrimental impact on the fuel. With JP-5, QCM showed slightly increased deposition with the JP-5 containing FAME but the deposition experienced was within the normal experience of JP-8s.

It is therefore generally concluded that FAME has no significant impact on either Jet A with the military package of additives or JP-8 or JP-5, although the data is less conclusive for the JP-5 than for the Jet A with the military package of additives and the JP-8.

2.0 INTRODUCTION AND BACKGROUND

AFRL recently completed a series of ARSFSS tests to evaluate the impact of FAME contamination on Jet A. The results from that program concluded that FAME contamination of up to 100 ppm has no discernible impact on the thermal stability of Jet A[1]. While these conclusions have not, at the time of the preparation of this report, been accepted by the fuels community at large, there is a high probability that eventually the Jet A specification will be modified to allow FAME contamination well beyond the current 5 ppm limit – largely based on the previous AFRL and University of Sheffield programs.

Parallel with this FAME contamination evaluation activity, the Air Force has begun a transition to make Jet A the standard fuel for all weapons systems[2]. The Air Force predicts it can save up to 2 cents per gallon by purchasing Jet A instead of JP-8. Jet A and JP-8 are nearly identical fuels with the only differences being the freeze point (-40 °C for Jet A, -47 °C for JP-8) and the additive packages used. Jet A uses no additives while JP-8 uses a standard military package (mil-pack) of additives consisting of fuel system icing inhibitor (FSII), corrosion inhibitor/lubricity improver (CI/LI), and a static dissipater additive (SDA). Antioxidant (AO) use is allowed in both Jet A and JP-8 but is typically only used when the fuel being treated has been heavily hydrotreated. JP-5 uses only CI/LI and FSII although AO is also allowed as with Jet A and JP-8. The JP-5 specification prohibits the use of SDA[3]. The current Air Force plan is that Bases will be converted to Jet A as their primary fuel and somewhere in the logistic supply chain, the standard mil-pack of additives will be added to the Jet A for use.

If FAME contamination beyond the current 5 ppm limit is allowed in Jet A, then that FAME contamination could be present in the Jet A used to supply Air Force users. Once additized with the mil-pack of additives, FAME would be in contact with the mil-pack additives. At this time, AFRL/RQTF is unaware of any substantial effort to define if the 100 ppm limit for FAME contamination is appropriate for Jet A or JP-8 that contains the mil-pack additives. It is inevitable that the question of FAME/Mil-Pack additive compatibility will be asked and the Air Force fuels community will need to be in a position to provide guidance based in data derived from specific testing.

In addition, with the allowance of increased contamination levels of FAME in Jet A, FAME material will likely be transported in the same conveyance as JP-5 – bringing with it the possibility of cross-contamination of FAME to the JP-5. Again, AFRL/RQTF is unaware of any substantial effort to look at the impact of FAME contamination in JP-5.

Therefore, AFRL/RQTF has initiated a preemptive limited evaluation of FAME in JP-8, JP-5 and additized Jet A so that when the question comes up, test data will be available to provide guidance for the response to these questions.

---

[1] *"Evaluation of the Impact of Fatty Acid Methyl Ester (FAME) Contamination on the Thermal Stability of Jet A". Morris, Jr. R. W., AFRL-RQ-WP-TR-2014-0017, November 2013*
[2] *Program Guidance Letter 12-03, Headquarters, Department of the Air Force, Michael B. Donley (Secretary of the Air Force); General Mark A. Welsh III, US Air Force Chief of Staff, June 4, 2013*
[3] *"DETAIL SPECIFICATION Turbine Fuel, Aviation, Grades JP-4 and JP-5", MIL-DTL-5624U, Notice 1, 4 Nov 2008*

3.0 PROGRAM GOALS AND OBJECTIVES

Data from a previously executed FAME-contamination test program will be leveraged in this program. The ARSFSS will be used in the EDTST-mode configuration and protocol. A limited selection of JP-5, JP-8 and mil-pack-additized Jet A fuels will be evaluated to determine the impact of up to 100 ppm FAME contamination in these fuels. Testing will be accomplished on baseline fuels and FAME-contaminated fuels containing 400 ppm FAME per ASTM D4054.

The overall goal of the program is to determine if 100 ppm FAME should be allowed in JP-8 or JP-5 or any Jet A fuel containing the mil-pack of additives. Results of these test will presented to the overall aviation fuel community as guidance.

4.0 EXPERIMENTAL

The overall test plan is summarized in the Table 2. The Run numbers in this table reflect the real-time order in which testing was accomplished. Table 2 also shows the fuel identification numbers of the fuel and additive used. Note that a base fuel blended with the FAME additive is considered to be a separate and new fuel ID.

4.1 Program Fuels:

4.1.1 Fuel Selection, Preparation and Management

FAME material for use as a contaminant was the same material used for the Jet A study recently completed[1] – POSF-8586. This FAME material is a blend of four common biodiesel (FAME) fuels from different feedstocks. All FAME contaminated fuels were prepared with this FAME material at a dosage rate of 400 ppm by volume.

Three fuels were selected based on current S-Farm inventory. They were as follows:

- Jet A (POSF-10325): This fuel was used in the previous FAME Contamination in Jet A study so this fuel was well characterized. Note that the previous study primarily used a FAME-sensitive jet fuel (POSF-9326). POSF-10325 is not this fuel.
- JP-5 (POSF-10289): This fuel was a typical JP-5.
- JP-8 (POSF-10264): This was a standard mil-spec JP-8 and was used to evaluate impact of FAME in an off-the-shelf JP-8.

Of these three fuels, only the Jet A (10325) required special preparation. For baseline testing, the standard mil-pack of additives was added to this fuel to represent a typical Jet A containing additives required for military use. For this program, AO was not used since AO is an allowed additive but not a mandatory additive. The mil-pack additives were added at the following concentrations:

Table 1: Additization Rates

Additization Rate for Military Package (Mil-Pack) Additives	
Additive	*Dosage*
Corrosion Inhibitor/Lubricity Improver (CI/LI)	16 mg/L
Antioxidant (AO)	Not Used
Static Dissapater Additive (SDA)	1.2 mg/L
Fuel System Icing Inhibitor (FSII)	0.09% by Volume

Table 2: ARSFSS Runs as Executed

Run No.	Test Description	Protocol	Fuel Type	Fuel Qty (gal)	FAME ppm	FCOC Bulk Inlet °F	BFA Bulk Inlet °F	BFA Max WWT °F	Spec Test	JFTOT Breakpoint	QCM	Notes
112	Jet A 10325+MP[1]	EDTST	Jet A	250	0	350	375	510	2 (see note)	2 (see note)	4 (see note)	Test the baseline stock fuel (10325) as well as the baseline stock fuel + Mil-Pack to assess any degradation in thermal stability due to the mil-pack
113	Jet A 10325+MP[1] + 400 ppm FAME	EDTST	Jet A	250	400	350	375	510				
114	Jet A 10325+MP[1]	EDTST	Jet A	250	0	350	375	510				Optional Repeat baseline to establish repeatability
115	JP-8 10264	EDTST	JP-8	250	0	350	375	510	1	1	2	
116	JP-8 10264 + 400 ppm FAME	EDTST	JP-8	250	400	350	375	510				
117	JP-8 10264	EDTST	JP-8	250	0	350	375	510				Optional Repeat baseline to establish repeatability
118	JP-5 10289	EDTST	JP-5	250	0	350	375	510	1	1	2	
119	JP-5 10289 + 400 ppm FAME	EDTST	JP-5	250	400	350	375	510				
120	JP-5 10289	EDTST	JP-5	250	0	350	375	510				Optional Repeat baseline to establish repeatability
										4		At completion of all testing, re-run JFTOT breakpoint on all baseline fuels including base blending stock (10325) to check for degradation. See Test Plan for specifics.
	Fuel Required ===>			**2,250**								

Notes:

1. MP = Military Additive Package (FSII, CI/LI, and SDA) added to Mil-DTL-83133 specifications

4.2 ARSFSS Preparation

The ARSFSS was operated in Extended Duration Thermal Stability Test (EDTST) mode for this program. Readers are referred to Technical Report AFRL-RQ-WP-TR-2014-0017, "Evaluation of the Impact of Fatty Acid Methyl Ester (FAME) Contamination on the Thermal Stability of Jet A," for a more detailed description of the ARSFSS modes of operation. In the EDTST mode, the ARSFSS operates in at steady-state conditions of:

- Bulk Fuel Temperature at inlet to FCOC = 325 °F
- Bulk Fuel Temperature at inlet to BFA = 375 °F
- BFA Wetted Wall Temperature = 510 °F
- Test Duration: 72 hours
- Test Preparation:
  - Pre-test hysteresis on FDV and Servo Valves
  - Clean pictures of test articles (FDV components, Servo Components, etc.)
  - Fuel blending, sampling, and analysis to assure uniform feed fuel
- Post-Test Analysis
  - Typical post-test hysteresis measurements
  - Photographs of test articles
  - Historical Data Dump to spreadsheet and analysis.

Each EDTST-mode Run required approximately 250 gallons of fuel. S-Farm Tanks S-3 and S-4 were the primary Run tanks with S-3 used as the run-tank for the non-FAME-additized baseline fuels. Tank S-4 was used as the run-tank for all FAME-contaminated fuels since this tank had already been contaminated with FAME from previous testing.

A minimal of fuel sampling was required or the program. Fuel samples were taken as follows:

- FAME-contaminated fuels were sampled and analyzed to confirm that FAME levels in the bulk fuel is at the appropriate level.
- Each baseline fuel as sampled and specification testing was performed, including JFTOT Breakpoint. Quartz Crystal Microbalance (QCM) testing was also accomplished on these samples
- Fuel Jet A 10325+Mil-pack was spec tested to assure that the additized fuel meets JP-8 spec with the exception of freeze point once the mil-pack of additives was added.

5.0 Results and Data-Specific Discussions

Generally, all ARSFSS Runs were executed without issue with the exception of Runs 112 and 117. In these runs, component failures required the test be shut down and restarted after repairs were made. Data plots post-test indicate that these test anomalies did not adversely affect the results of the tests based on the BFA temperature trends observed.

5.1 Breakpoint Determinations on Program Fuels

Table 3 shows the JFTOT Breakpoints of the fuels used in the program:

Table 3 JFTOT Breakpoints on Program Fuels

JFTOT BREAKPOINT DETERMINATIONS*		
Fuel Type	***Fuel***	***Breakpoint Temperature***
Jet A	POSF - 10325	290 °C
JP-8	POSF - 10264	295 °C
JP-5	POSF - 10289	285 °C / 290 °C **
Jet A + Mil-pack	POSF - 10350	285 °C
Jet A + Mil-Pack + 400 ppm FAME	POSF - 11039	Not Determined
JP-8 + 400 ppm FAME	POSF - 11585	Not Determined
JP-5 + 400 ppm FAME	POSF - 11679	Not Determined
** ASTM D3241*		
*** Two determinations*		

JFTOT determinations were not made on FAME-contaminated fuels because previous test programs indicated there was no impact on the Breakpoint of fuel from FAME. As can be seen all of the base fuels used in the program had JFTOT Breakpoints at 290 °C ± 5 °C. This indicates that all fuels used in the program were of high quality.

5.2 ARSFSS Run Discussions

All ARSFSS testing for this program was accomplished using the steady-state Extended Duration Thermal Stability Test protocol. In this protocol, Bulk Fuel Temperature at inlet to FCOC was set to 325 °F. Heat loading of the FCOC was set to achieve a Bulk Fuel Temperature at the inlet to the BFA of 375 °F. BFA heat loading was set to achieve a BFA Wetted Wall Temperature (WWT) of 510 °F. Within the first two missions, the power setting for the BFA necessary to achieve this 510 °F wetted-wall temperature was locked-in to maintain constant heat input through the duration of the test, which was 72 hours. Any increase in WWT after that point is indicative of coking on the inside wall of the BFA.

5.2.1 Evaluation of FAME in a Jet A with Military Package Additives

5.2.1.1 Fuel-Cooled-Oil-Cooler (FCOC) and Burner Feed Arm (BFA) Deposition

Testing for the program was initiated with baseline Jet A with the Military Package (MP) testing in Run 112. A little over half-way through this Run, the RF Heater for the BFA failed. The heater was repaired and the Run was restarted (See Figure 1). This shutdown is represented by the downward blip shown in Figure 1.

The rate of temperature rise in the thermocouples after the temporary shutdown seems to be greater than in the first part of the test before the shutdown indicating that the shutdown may have resulted in initiation of coking in the BFA. However, this general trend of the temperatures (a more pronounced temperature rise in the last half to last quarter of the Run than in the first half or first three-quarters of the Run) has been observed frequently when no shutdown occurred and is considered normal for a fuel that gives deposition in the BFA at these conditions. Based on this experience, it can be concluded that this shutdown and restart had no detrimental effect on the overall test. The overall temperature rise in BFA WWT for Run 112 was 12 °F to 15 °F depending upon which thermocouple is viewed.

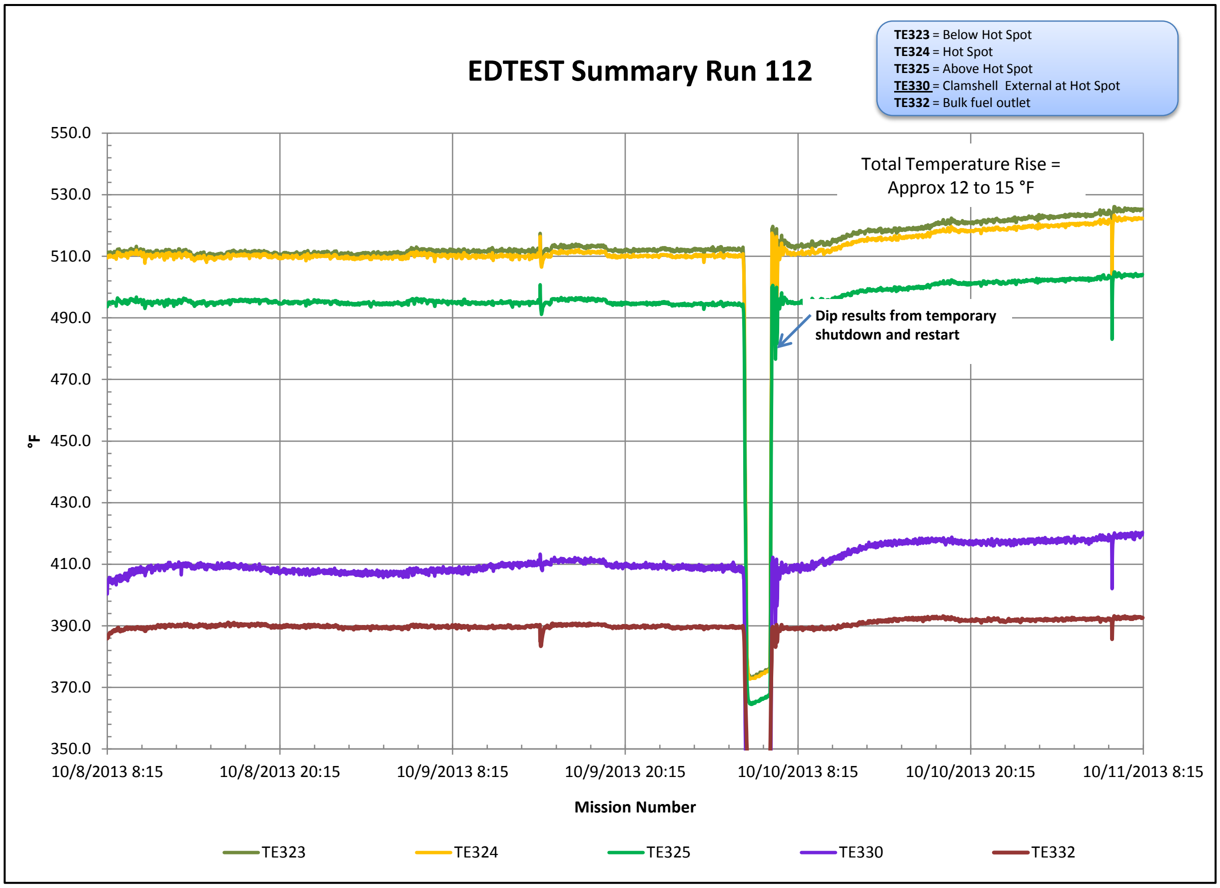

Figure 1 - WWT Profile During Run 112 Temporary Shutdown and Restart

Run 113 was a duplicate of Run 112 using the same baseline fuel (Jet A+MP). The BFA temperature plot is shown in Figure 2. It can be seen that the rate of rise in BFA WWT is similar in both Runs 112 and 113. Run 113 resulting in overall BFA WWT rise of about 15 °F . This further validates the determination that the mid-Run shutdown and restart in Run 112 had no detrimental effect on the results of that test.

Run 114, the FAME-contaminated Run, was performed at the same conditions as Runs 112 and 113 with the test fuel being the same Jet A+MP as well as 400 ppm FAME (Jet A+MP+FAME). Figure 3 shows the WWT temperature plot for this Run. The WWT temperature rise for this Run was 10 °F which was 2 °F to 5 °F less than for the baseline Jet A+MP Run. At a minimum this indicates no detrimental impact of FAME on this fuel. Indeed, it could be argued that the presence of FAME had a slight positive impact on BFA deposition (a reduction in BFA deposition). This would not be inconsistent with findings in the previous FAME contamination work on Jet A[1].

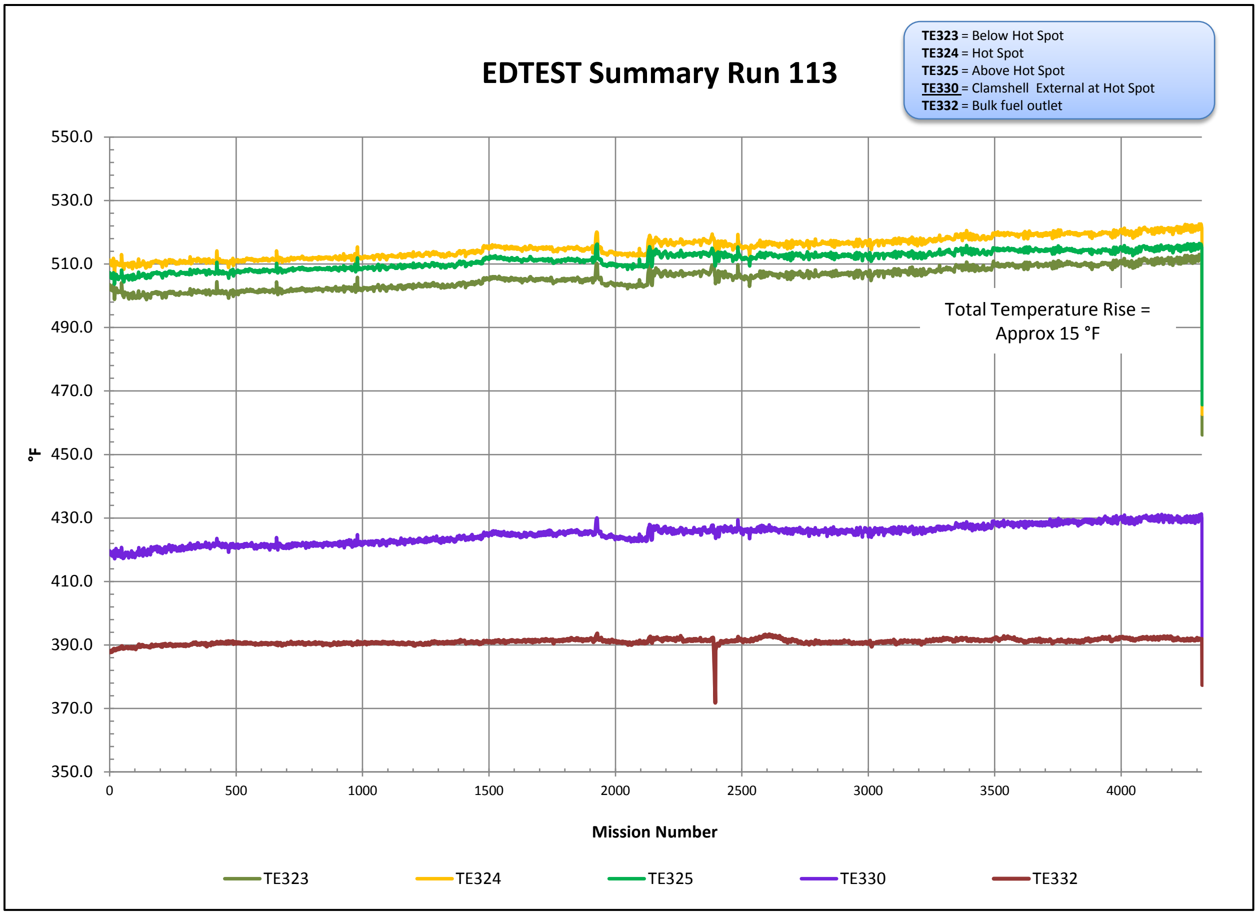

Figure 2 - WWT Profile During Run 113

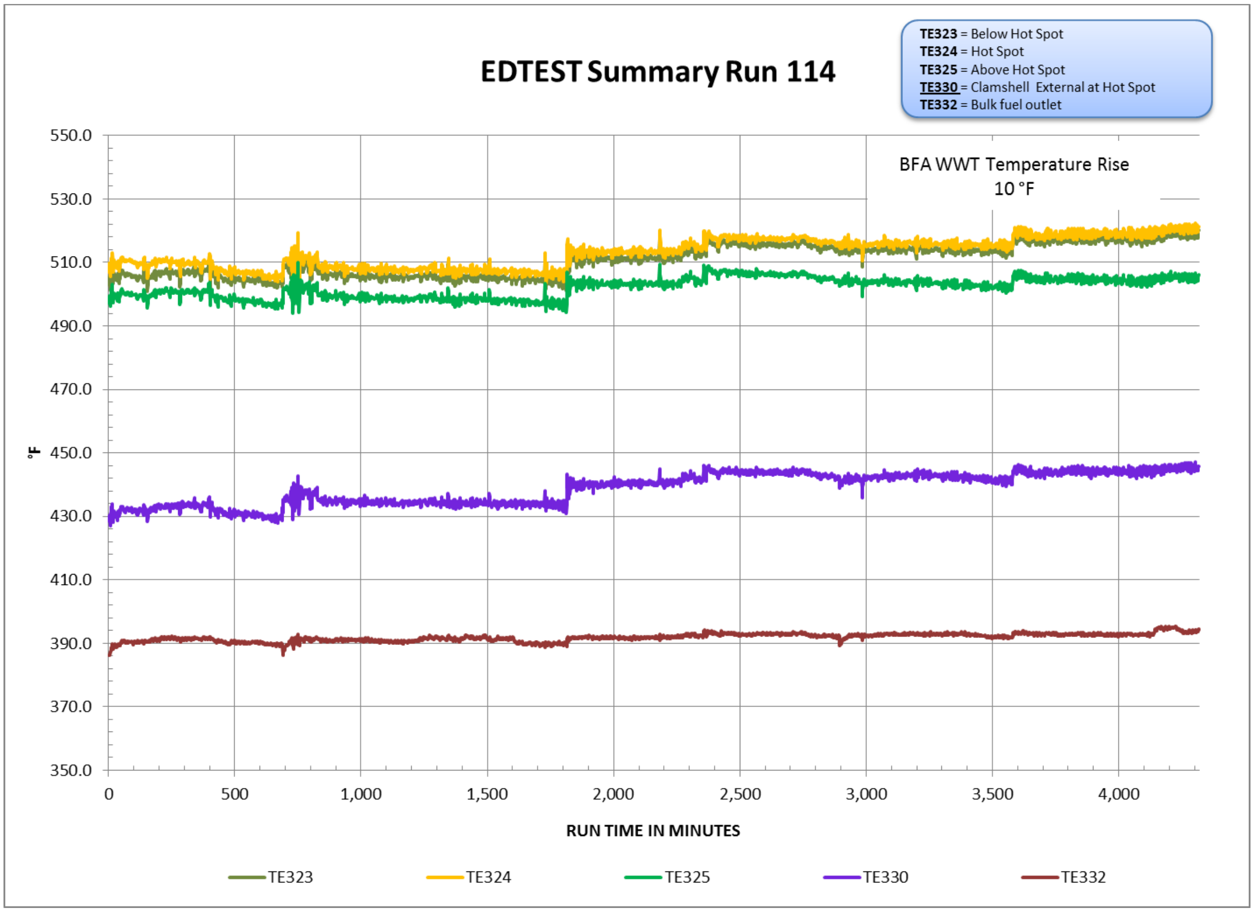

Figure 3 - WWT Profile During Run 114

Figure 4 shows the measurement of effective carbon deposition in the Fuel-cooled-Oil-Cooler (FCOC) for Runs 112, 113 and 114. Effective carbon deposition takes into account the background carbon measured in the FCOC tube metal itself. Figure 5 shows the measurement of effective carbon deposition in the Burner Feed Arm (BFA) for Runs 112, 113 and 114.

Run 113 showed unusual deposition trends in both the FCOC and the BFA. In each device, deposition was much more pronounced in the entrance and preheat areas of the FCOC and BFA tubes than in the latter parts of the tubes toward the exits. However, the consistently steady rise in BFA WWT is counter indicative of this observation. This behavior is not normally observed for these devices – in fact this may be the first time this phenomena has been observed, at least to this degree.

Comparing deposition produced by the Jet A+MP fuel versus the FAME-contaminated fuel, in both the FCOC and BFA the deposition seems to be very similar (of course with the exception of the anomaly of data in the last half of the FCOC and BFA for Run 113). From these plots, it can be concluded that there does not seem to be an adverse effect upon coking from the FAME-contaminated fuel.

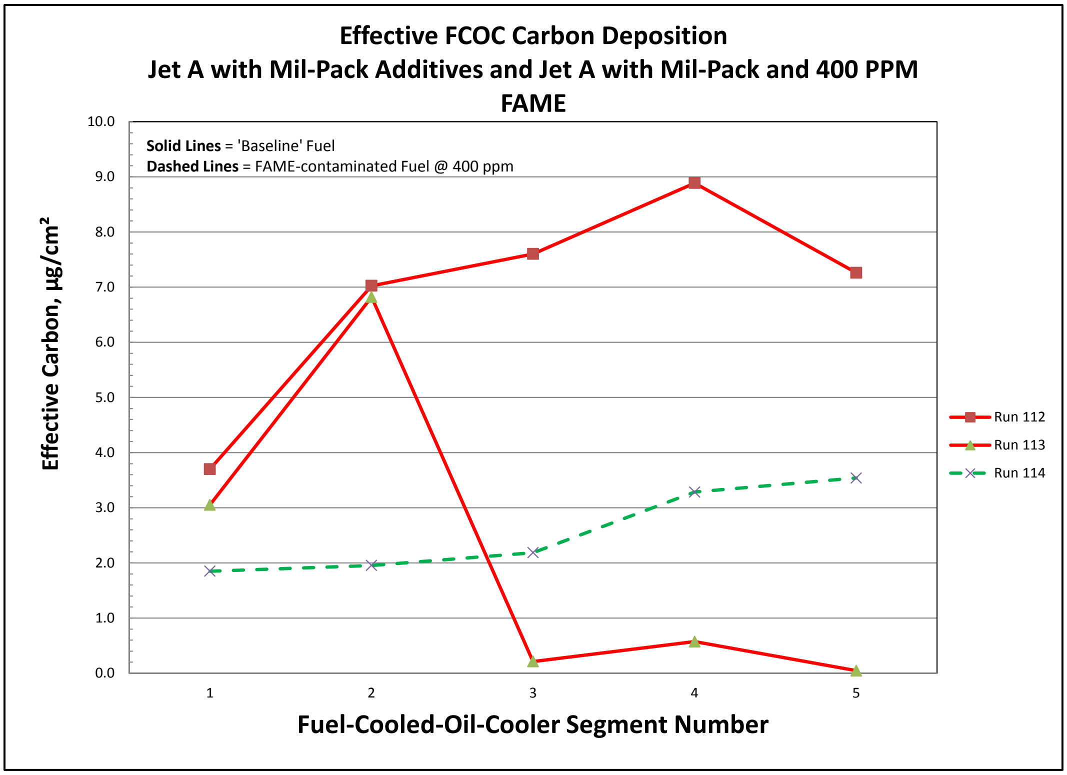

Figure 4 - Effective Carbon Deposition in FCOC, Runs 112, 113 and 114

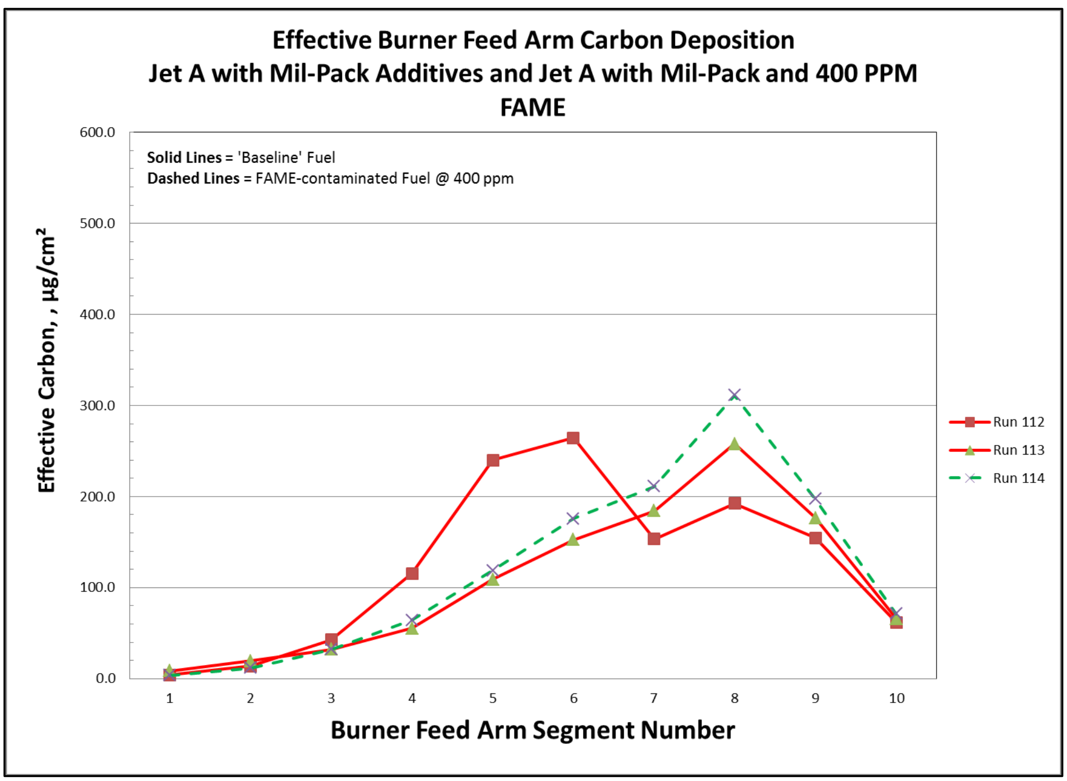

Figure 5 - Effective Carbon Deposition in BFA, Runs 112, 113 and 114

5.2.1.2 Servo Valve (SV) and Flow Divider Valve (FDV) Hysteresis

Figures 6 and 7 show the hysteresis in the Servo Valve subjected to non-FAME-contaminated fuel (Jet A+MP). The post-test spread for the flow measurement is slightly increased from the pre-test spread. However, when compared to Figure 8 showing the hysteresis measured when the Servo Valve is subjected to that same fuel with FAME contamination, it is seen that hysteresis in this case is virtually non-existent. These results are consistent with FCOC and BFA deposition findings as well as BFA WWT rise.

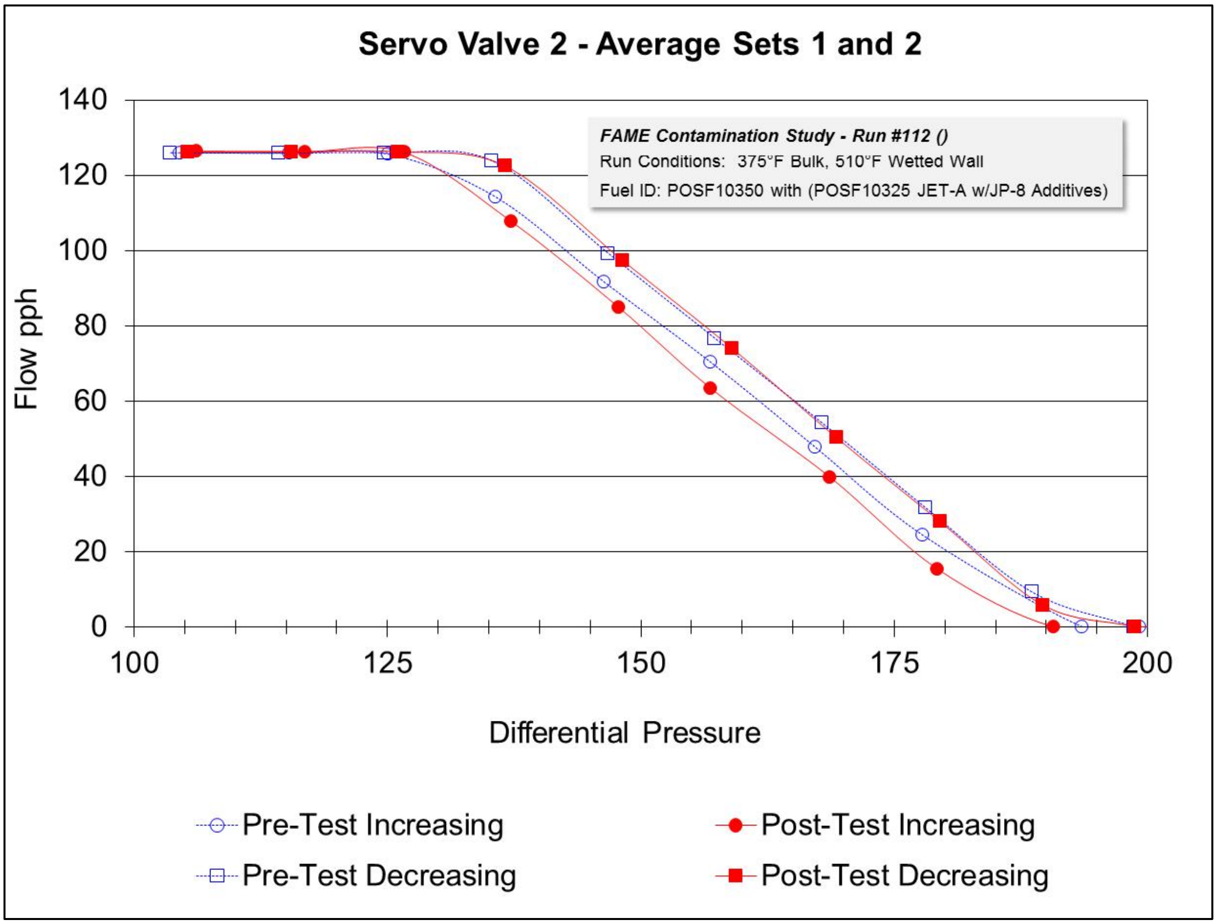

Figure 6 - Servo Valve Hysteresis Measurement, Run 112

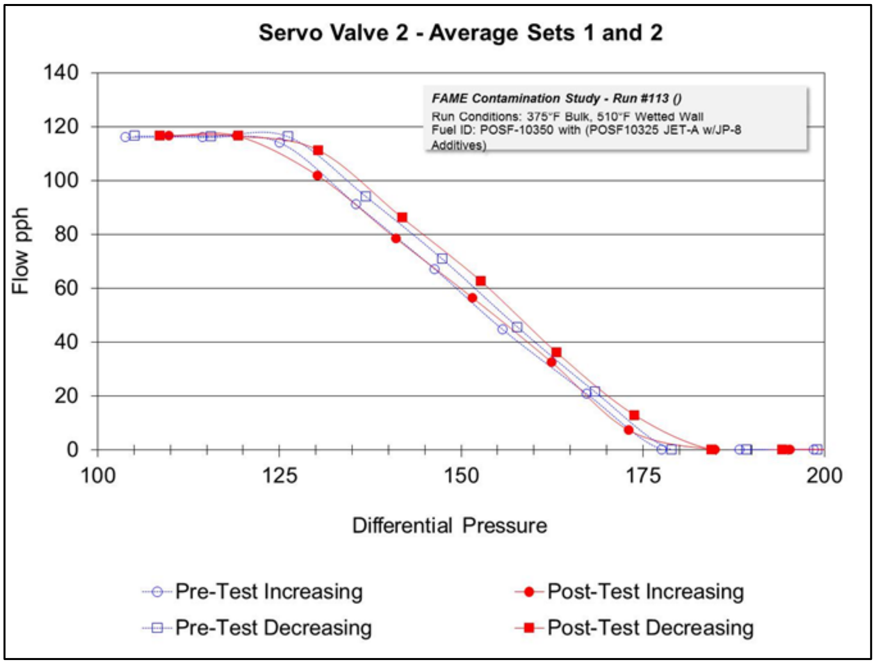

Figure 7 - Servo Valve Hysteresis Measurement, Run 113

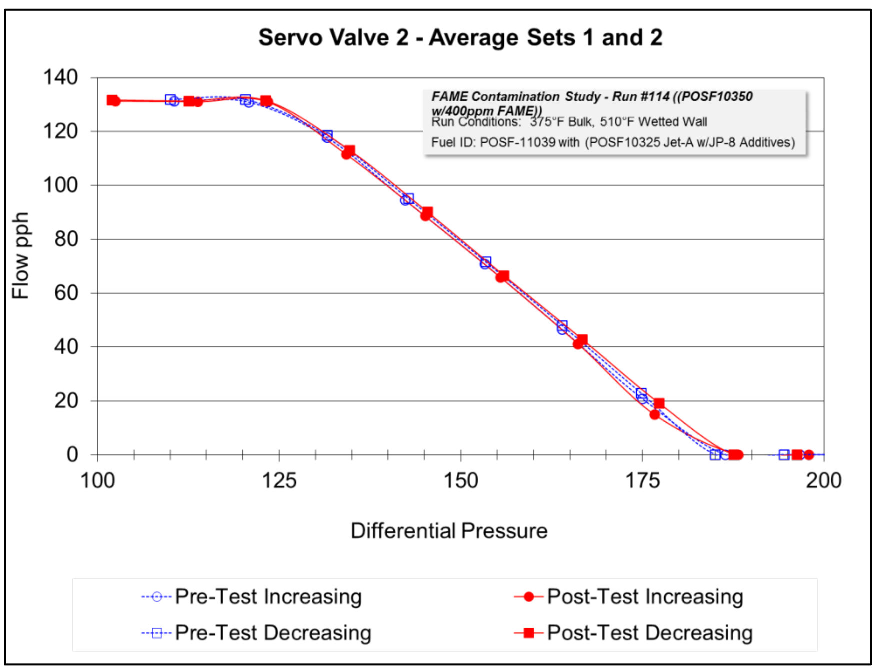

Figure 8 - Servo Valve Hysteresis Measurement, Run 114

Figures 9 and 10 show the hysteresis in the Flow Divider Valve (FDV) subjected to non-FAME-contaminated fuel (Jet A+MP). The post-test spread for the flow measurement is slightly decreased from the pre-test spread. The hysteresis measured for Run 113 shows little or no hysteresis change from pre- to post-test. The plot of Run 114 FDV hysteresis again, reveals little or no hysteresis indicating no negative impact of the FAME contamination. As with the SV, these results are consistent with FCOC and BFA deposition findings as well as BFA WWT rise.

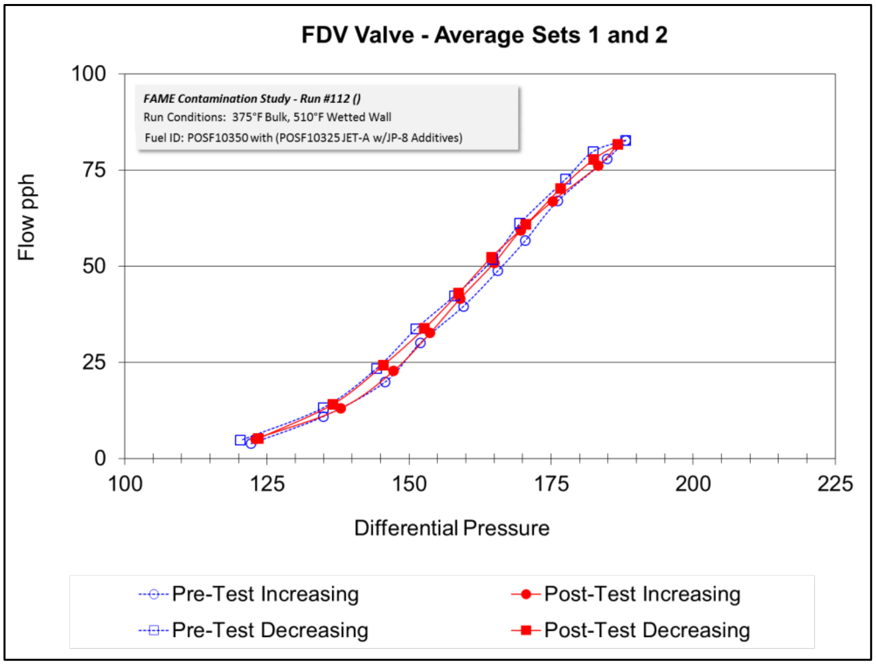

Figure 9 - FDV Hysteresis Measurement, Run 112

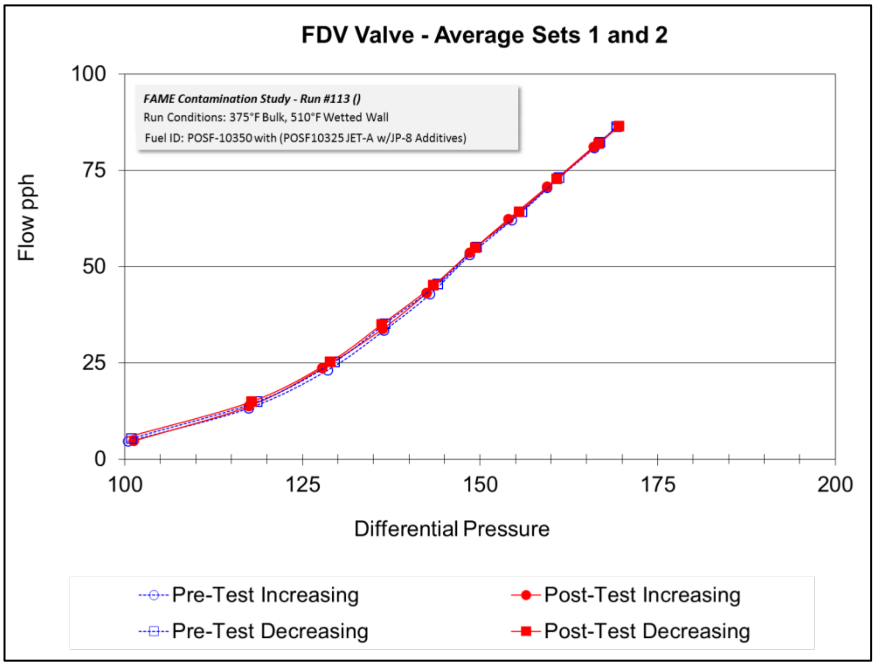

Figure 10 - FDV Hysteresis Measurement, Run 113

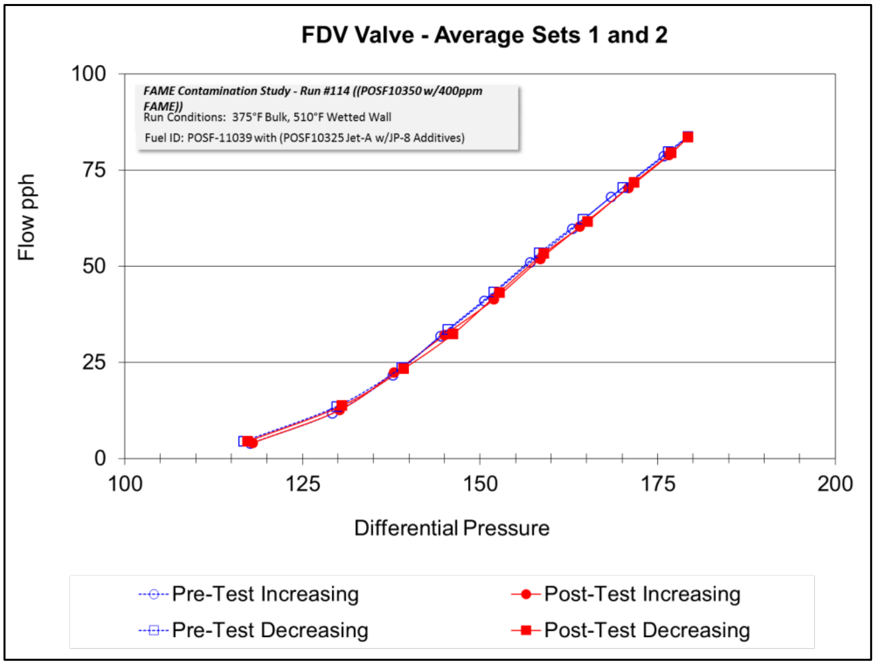

Figure 11 - FDV Hysteresis Measurement, Run 113

5.2.1.3 Visible Deposition in Fuel-Wetted Components

Figures 12 through 15 present images of fuel-wetted components used in the ARSFSS to provide a visual comparison of deposition. Figure 12 shows deposition appearance in the SV, Figure 13 shows deposition appearance in the FDV components. Figure 14 shows the appearance of the filter at the HP Pump inlet and Figure 15 shows deposition appearance in the Nozzle Simulator (NS) device. The NS is similar to the Torque Motor Screen in the Aviation Fuel Thermal Stability Test Unit (AFTSTU) located at the University of Sheffield in the UK.

In Figures 12 and 13, there appears to be light deposition in the SV and FDV components with the Jet A+MP fuel. There appears to be little or no deposition in these same components when using FAME-contaminated fuel. Figure 14, while not showing deposition on a metal surface, seems to also show less material trapped in the HP Pump filter (less bulk-fuel deposition) for Jet A+MP than for the FAME-contaminated fuel. Again, this is consistent with findings in prior ARSFSS programs involving FAME contamination. In Figure 15, there appears to be no difference in the appearance of deposition for either of the fuels. This leads to the conclusion that there is no negative impact of FAME for this particular fuel.

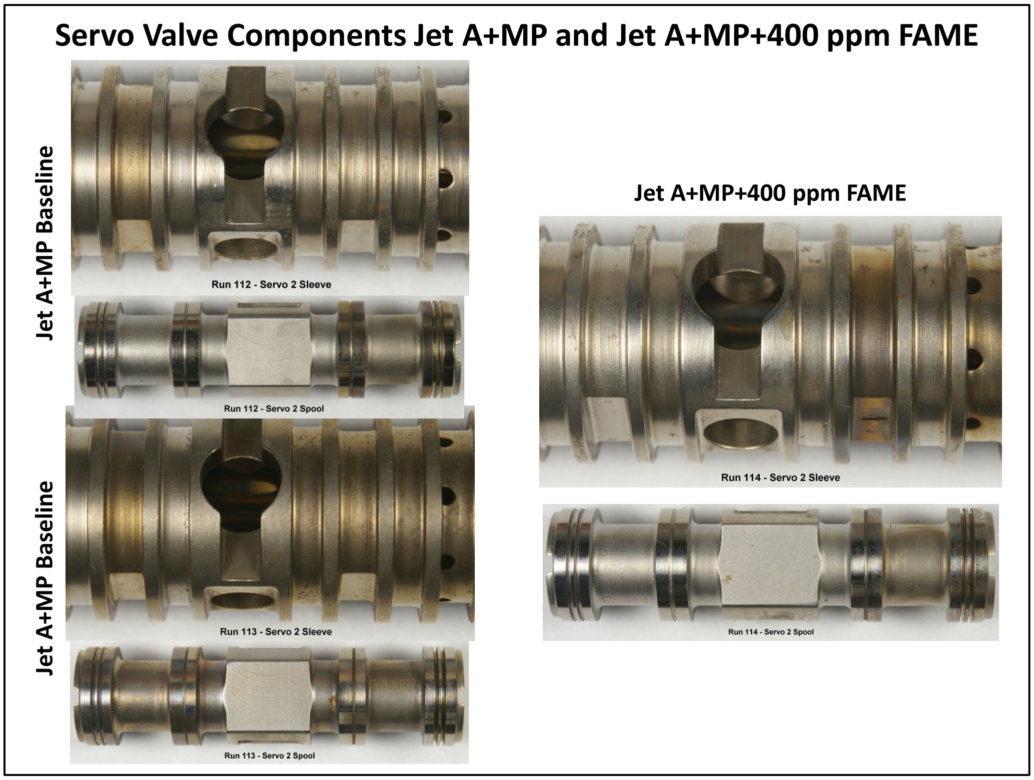

Figure 12 - Visible Deposition in the SV Components

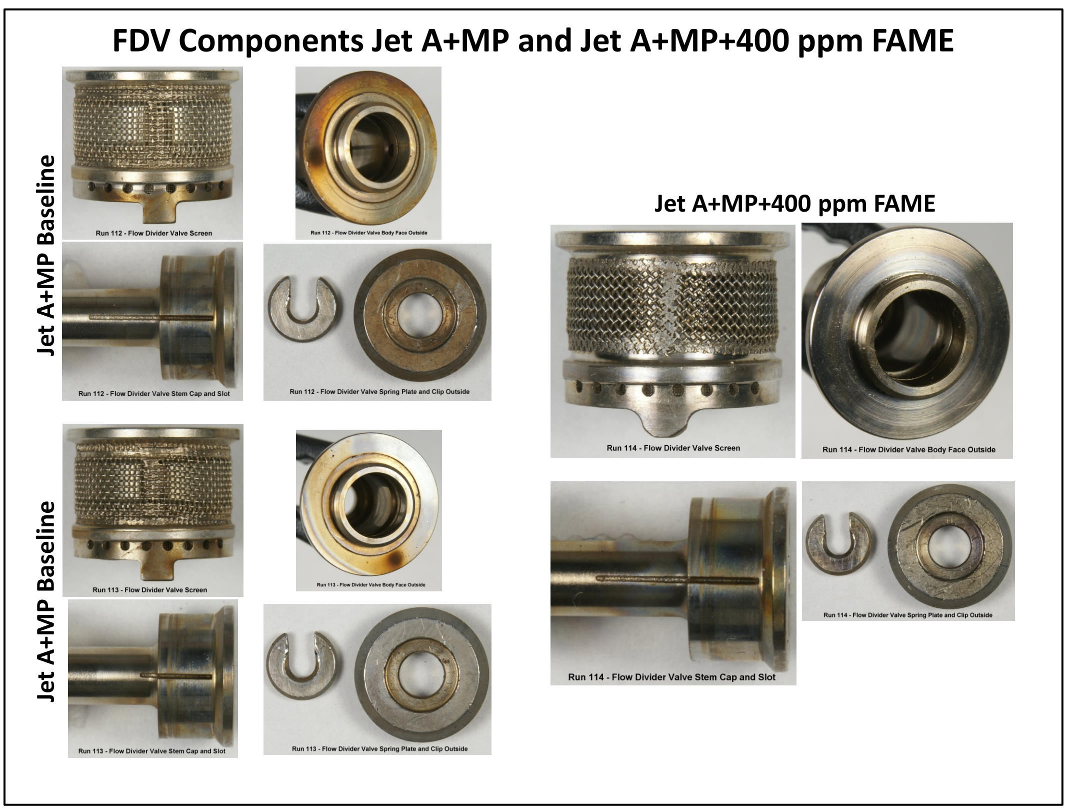

Figure 13 - Visible Deposition in FDV Components

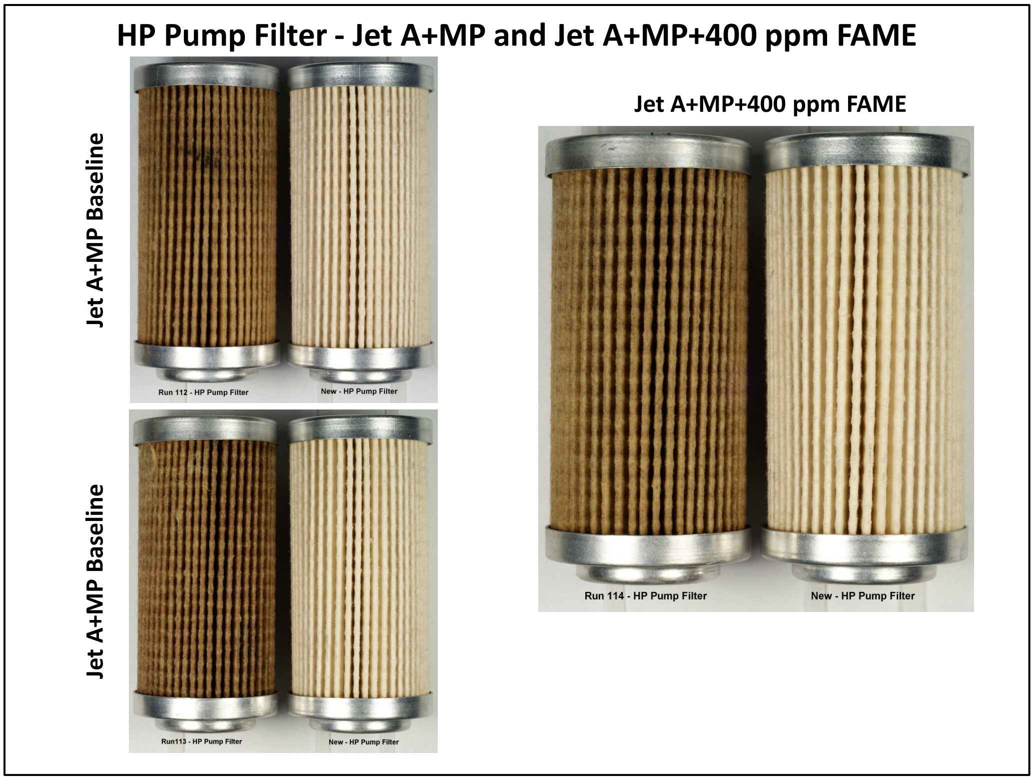

Figure 14 - Appearance of HP Pump Filter

Figure 15 - Visible Deposition in Nozzle Screen Components

5.2.2 Evaluation of FAME in a JP-8

5.2.2.1 FCOC and BFA Deposition

Figures 16 through 18 show the temperature history in the BFA for Runs 115 – 117. In Run 115 (Figure 16), the blips in the data plot represent anomalies introduced by an unstable RF heater for the BFA. These anomalies did not appear to impact the results of the run. There was no total temperature rise in this test. In Run 116 (Figure 17), the RF heater had resumed normal nominal operation after some maintenance the occurred between Run 115 and 116. The total temperature rise in this test was about 7 °F leading to some concern that the anomalies experienced in Run 115 may have indeed impacted the overall temperature rise experienced during that Run. In Run 117, the FAME-contamination run, Figure 18 shows another downward blip in the temperature data indicating a temporary shutdown and restart. In this case, at about 4.5 hours into the Run, the SV became unstable. Troubleshooting revealed an internal leak in the valve. The Run was paused, the SV was removed and disassembled. O-rings were replaced and reinstalled. System was restarted and Run was completed without further incident. The overall temperature rise for this test was between 3 and 4 °F depending upon which thermocouple was observed. It is not uncommon for the wetted-wall hot spot to shift from one thermocouple position to another. This is normally attributed to flow anomalies (recall that a pump failure was experienced in Run 112) or fuel deposits being laid down inside the BFA in a way that is slightly different from other tests.

Assessing the temperature data, it can be concluded that the presence of FAME in the JP-8 had no detrimental effect on the coking deposition. This is consistent with previous programs.

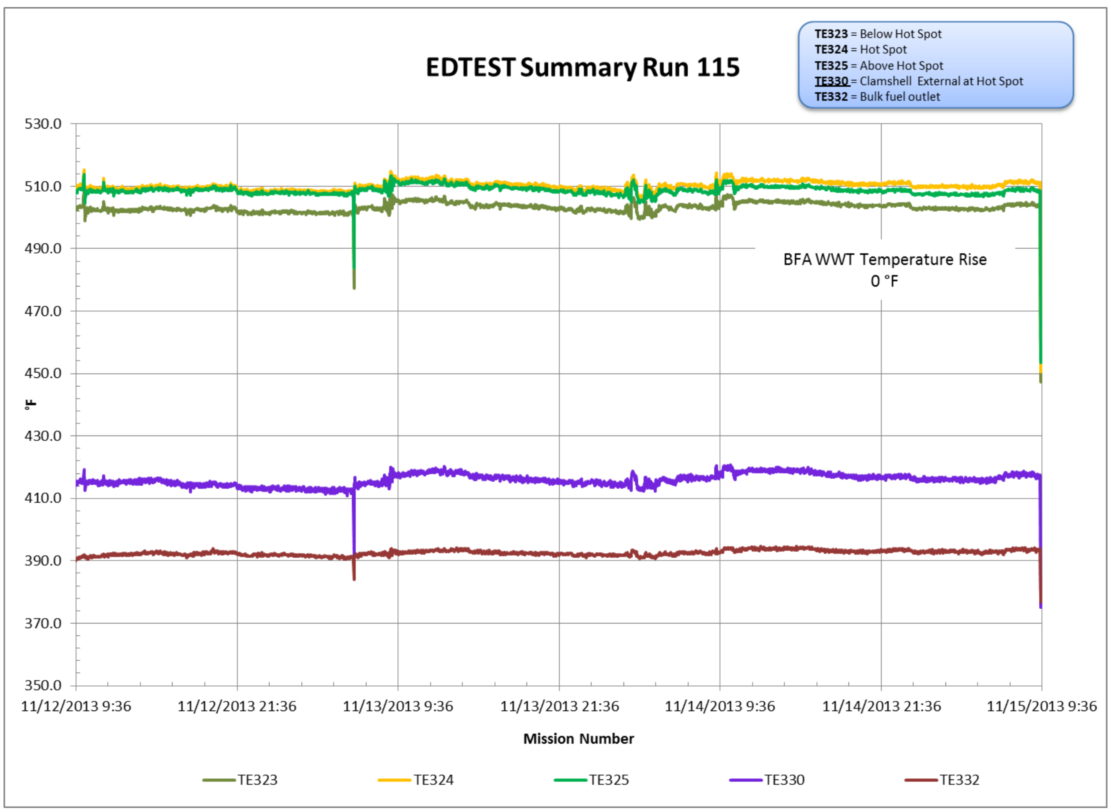

Figure 16 - BFA WWT Profile, Run 115

DISTRIBUTION STATEMENT A: Approved for public release. Distribution is unlimited.

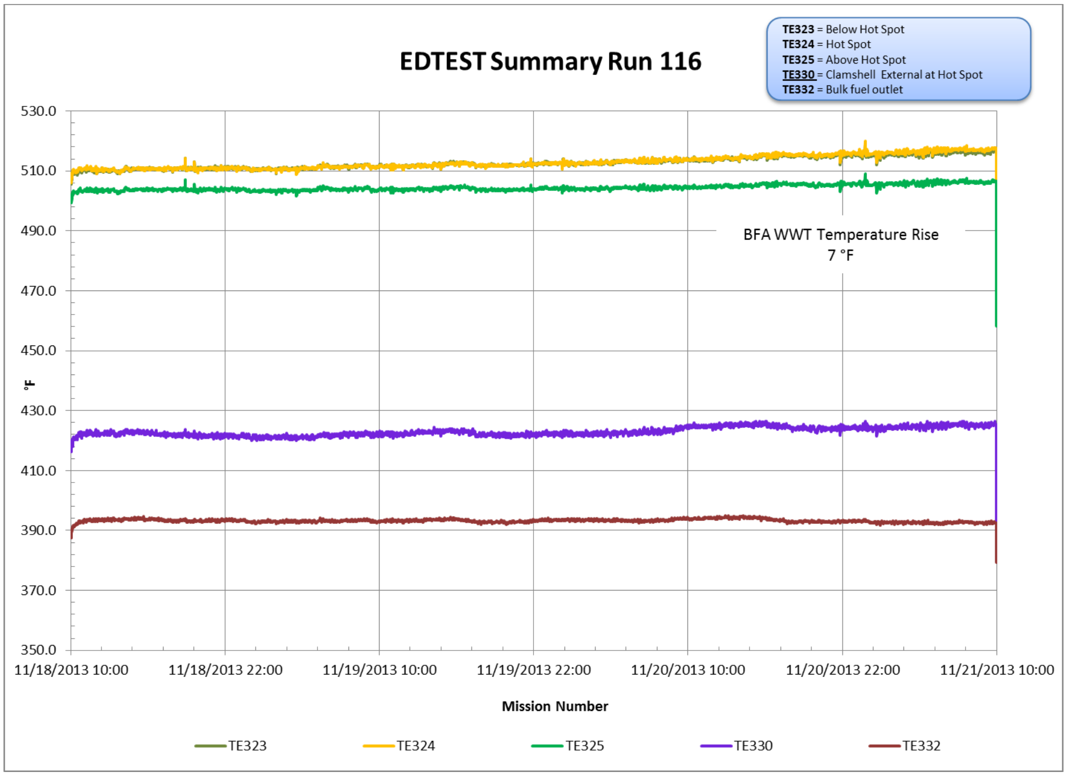

Figure 17 - BFA WWT Profile, Run 116

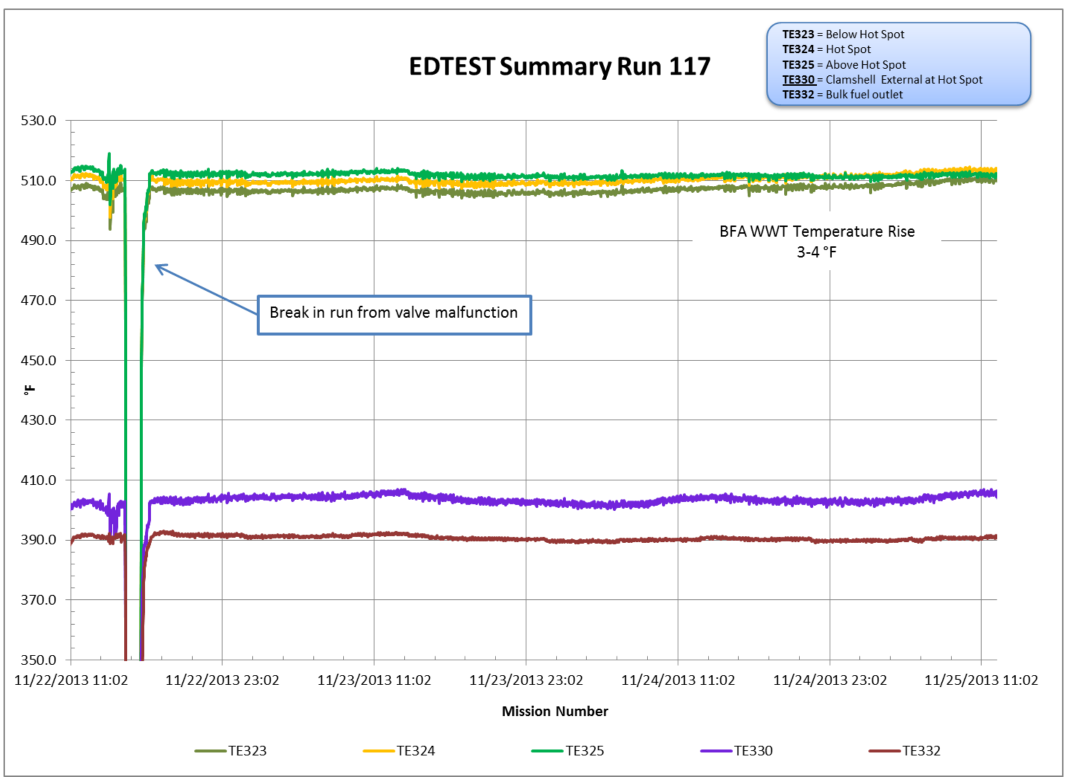

Figure 18 - BFA WWT Profile, Run 117

Figures 19 and 20 show the measurement of effective carbon deposition in the FCOC and BFA for Runs 115, 116 and 117. Effective carbon deposition takes into account the background carbon measured in the tube metal itself. Figure 19 shows a plot of FCOC deposition and what appears to be a high-deposit area in Zone 4 of the FCOC. However, when considering the scale of the plot, this really doesn't represent a spike deposition at all. Hence the plot shows that there is no impact on FCOC deposition from the FAME-contaminated fuel.

Figure 20 shows a plot of BFA deposition. The plot shows again that there is no impact of FAME contamination on the fuel. These findings for both the FCOC and the BFA are consistent with prior program data on this topic.

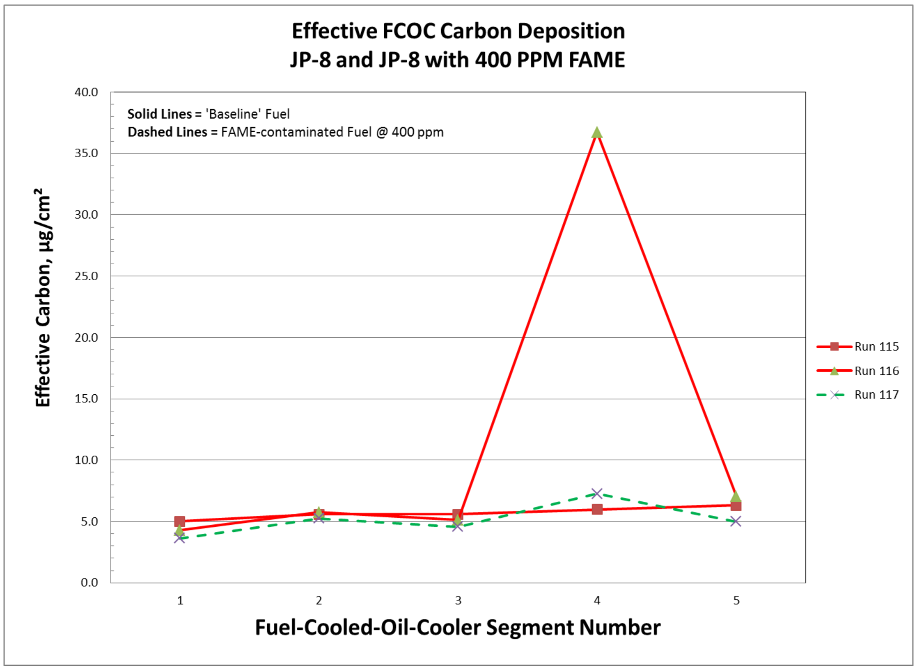

Figure 19 - Efective FCOC Carbon Deposition For JP-8 and JP-8 + FAME

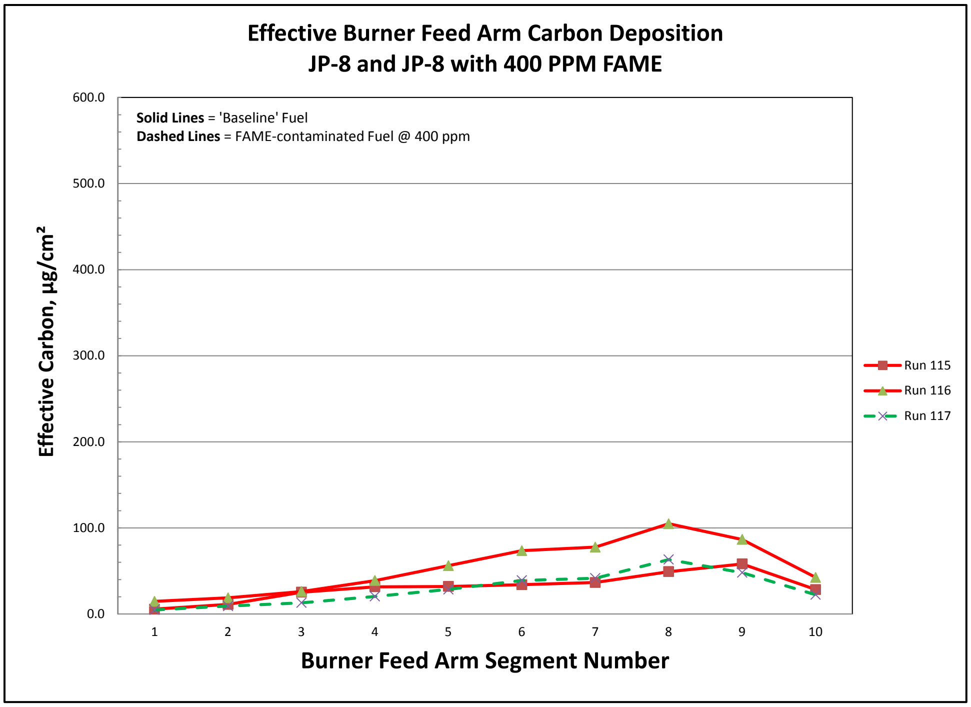

Figure 20 - Efective BFA Carbon Deposition For JP-8 and JP-8 + FAME

5.2.2.2 Servo Valve (SV) and Flow Divider Valve (FDV) Hysteresis

Figures 21 and 22 show the hysteresis in the SV subjected to non-FAME-contaminated JP-8. There is little to no post-test spread for the flow measurement when compared to the pre-test spread in Run 115. Only slightly more hysteresis is present in Run 116. However, this increased hysteresis is at the end of valve travel so it is more likely that this hysteresis was introduced by the valve itself and not the fuel since hysteresis pre- and post-test in the middle operating range of the valve is nonexistent. Figure 23 shows the hysteresis measured when the SV is subjected to that same JP-8 fuel with FAME contamination. As with Run 116, the small amount of hysteresis present is toward the end of the operating range of the valve, but not as far toward the end as with Run 116. Since hysteresis in the middle operating range of the valve is non-existent, it cannot be readily determined if the hysteresis experienced in the lower operating ranges is due to fouling in the valve or mechanical action inside the valve.

Figures 24 and 25 show the hysteresis in the FDV when subjected to non-FAME-contaminated JP-8. Figure 26 shows FDV hysteresis when using FAME-contaminated JP-8. In all cases, there is no change in FDV hysteresis leading to the conclusion that there is no detrimental impact of FAME for this fuel

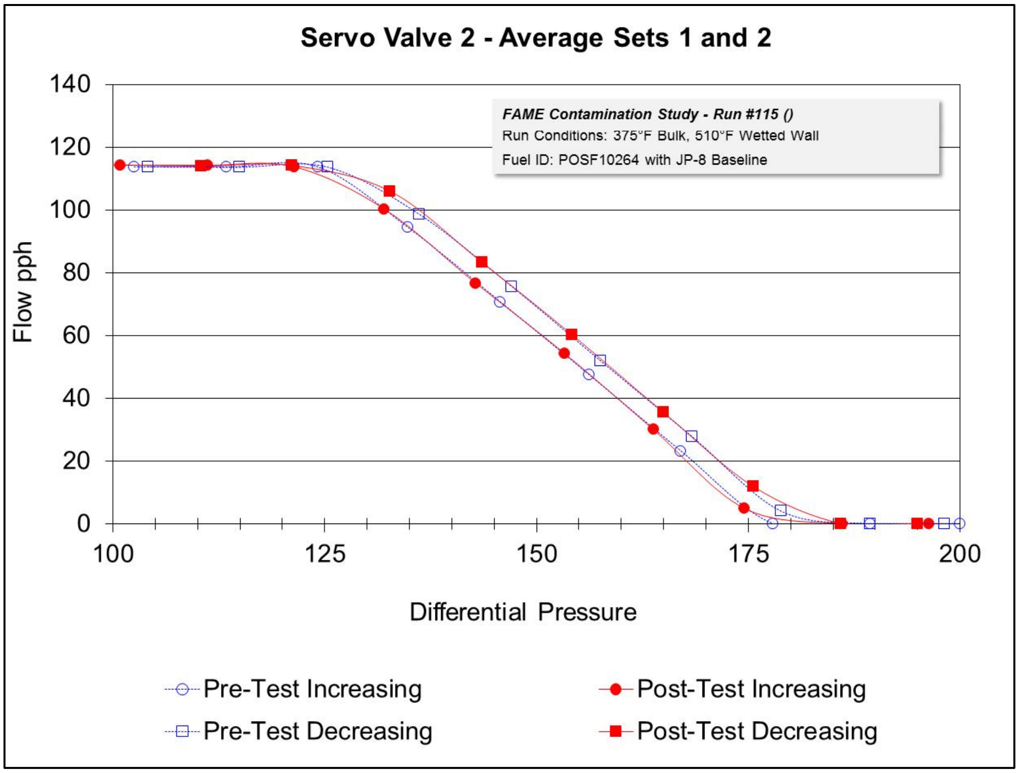

Figure 21 - Servo Valve Hysteresis with JP-8 Baseline Fuel

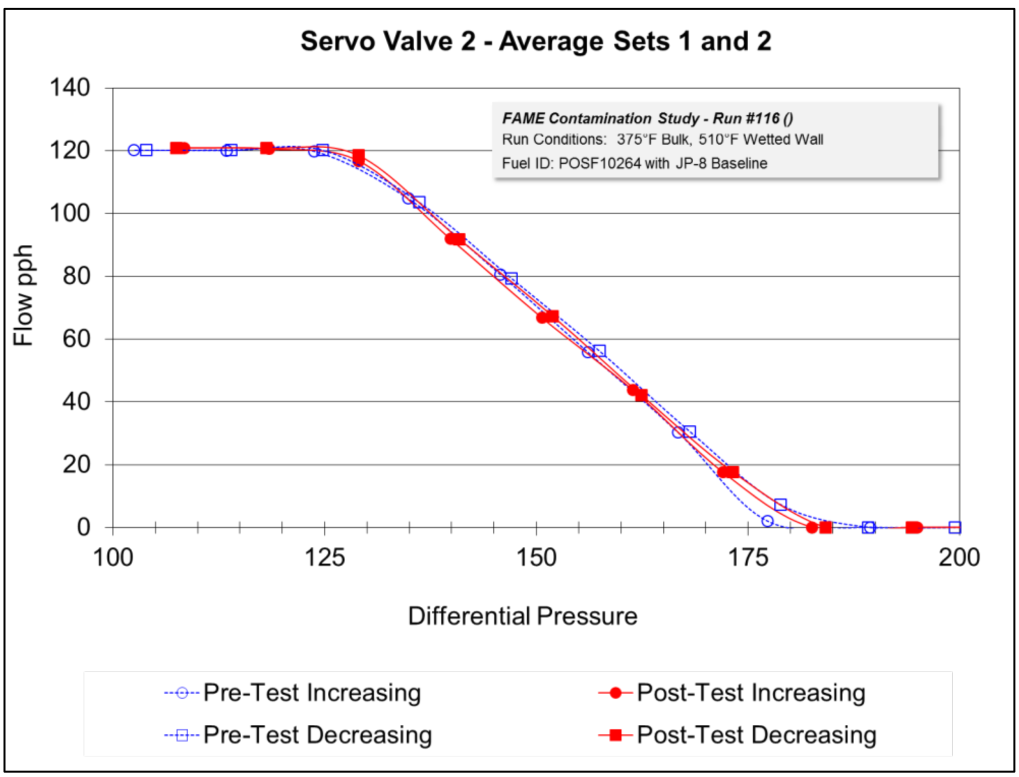

Figure 22 - Servo Valve Hysteresis With JP-8 Baseline

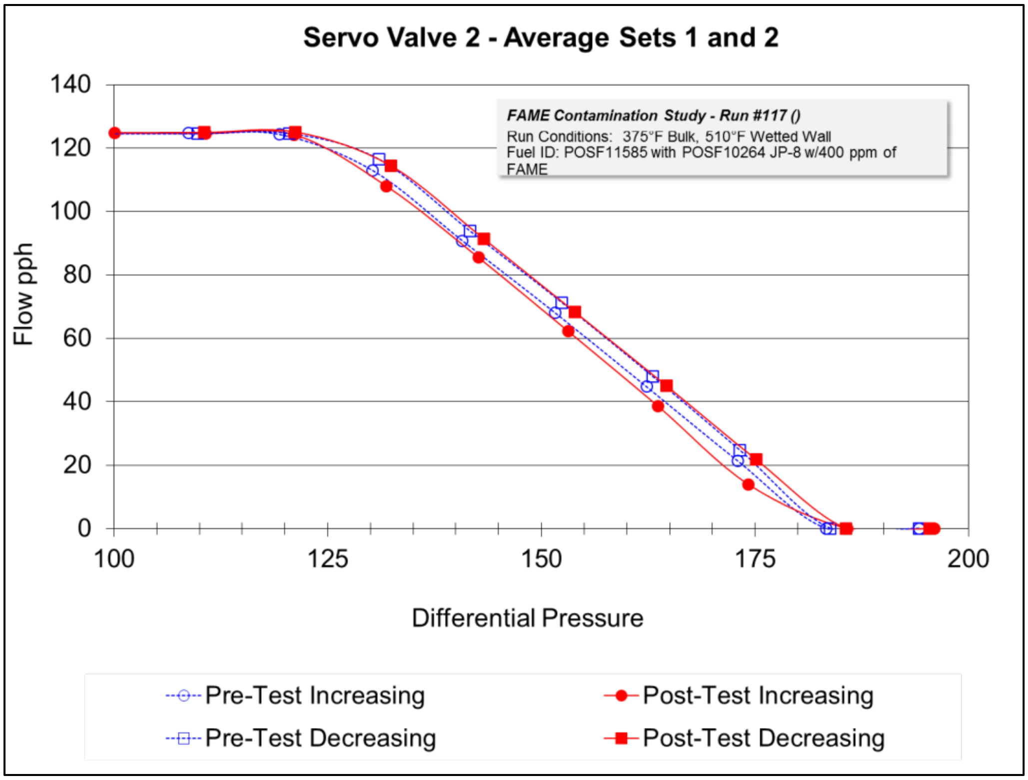

Figure 23 - Servo Valve Hysteresis For JP-8 with FAME Contamination

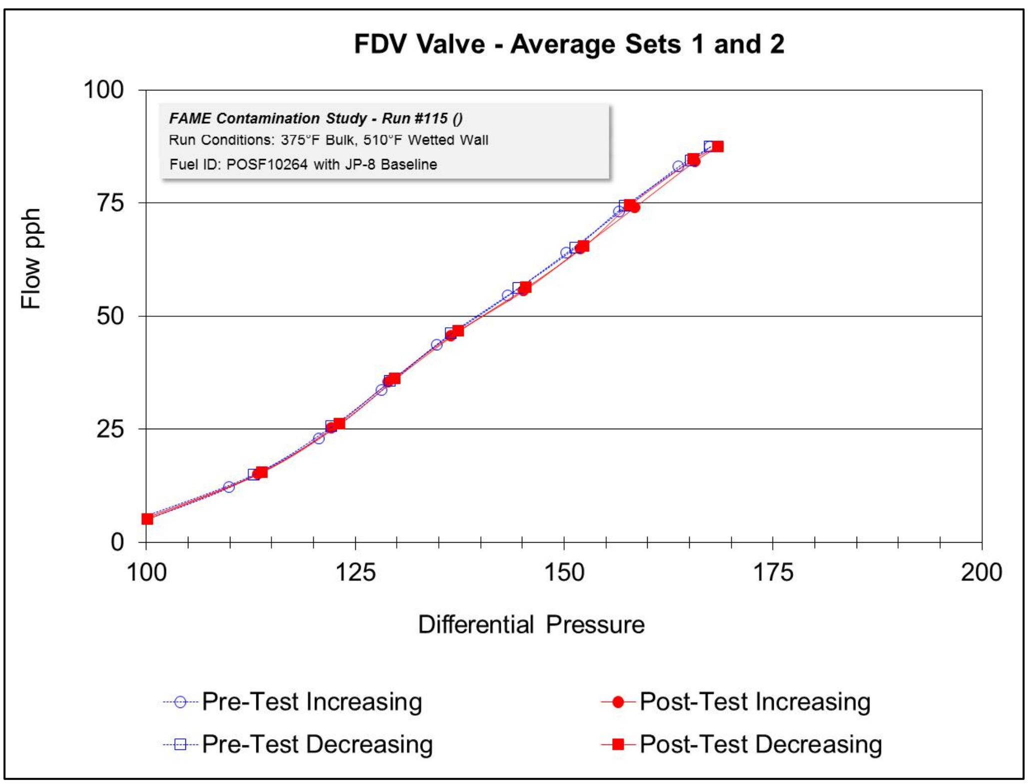

Figure 24 - FDV Hysteresis Using Baseline JP-8

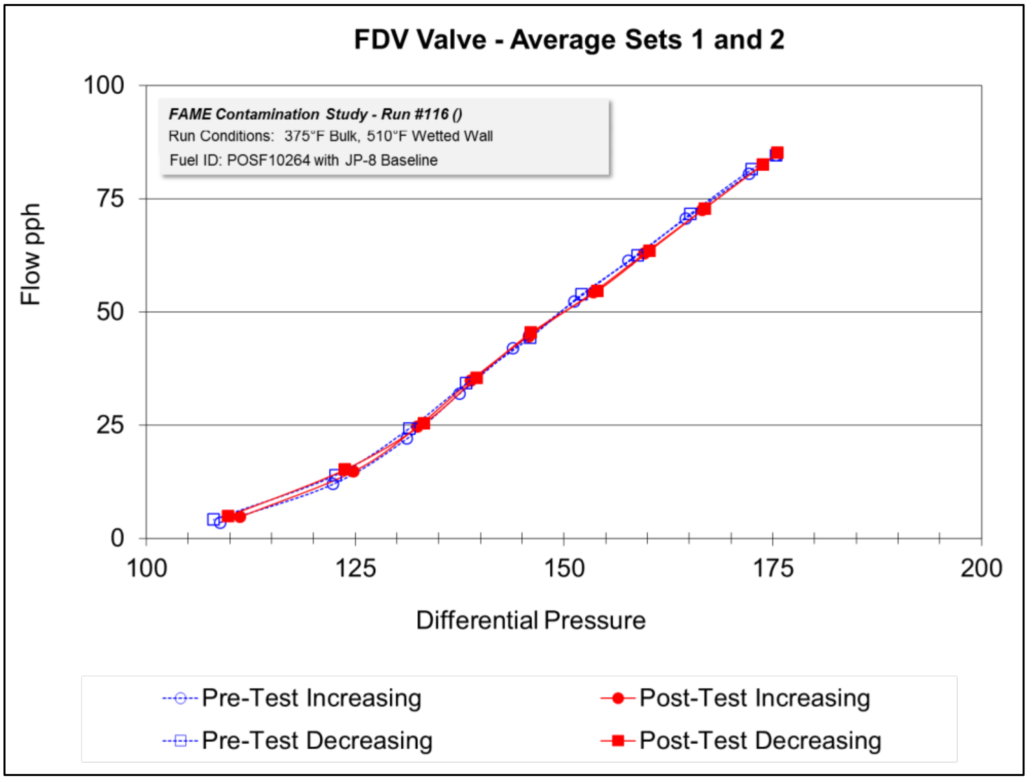

Figure 25 - FDV Hysteresis Using Baseline JP-8 (Repeat)

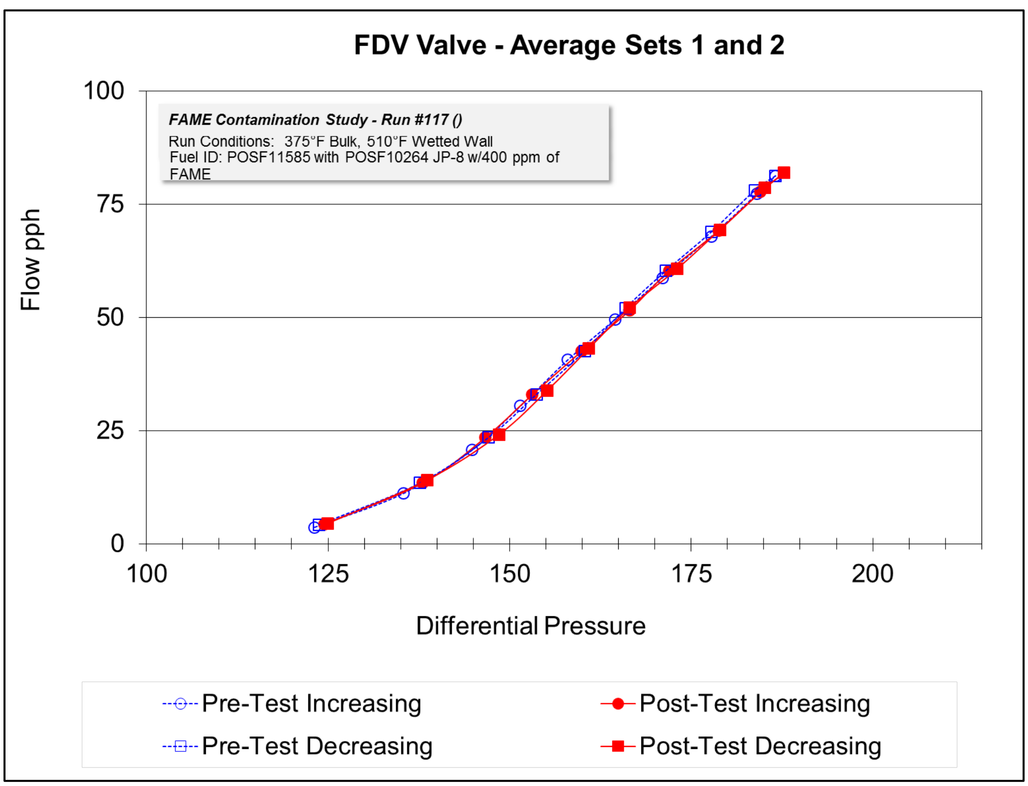

Figure 26 - FDV Hysteresis Using JP-8 with FAME Contamination

5.2.2.3 Visible Deposition in Fuel-Wetted Components

Figures 27 through 30 present images of fuel-wetted components used in the ARSFSS to provide a visual comparison of deposition. Figure 27 shows deposition appearance in the SV, Figure 28 shows deposition appearance in the FDV components. Figure 29 shows the appearance of the filter at the HP Pump inlet and Figure 30 shows deposition appearance in the nozzle Simulator (NS) device. The NS is similar to the Torque Motor Screen in the Aviation Fuel Thermal Stability Test Unit (AFTSTU) located at the University of Sheffield in the UK.

In Figures 27 and 28, there appears to be light deposition in the SV and FDV components with the Jet A+MP fuel. There appears to be little or no deposition in these same components when using FAME-contaminated fuel. Figure 29, while not showing deposition on a metal surface, seems to also show less material trapped in the HP Pump filter (less bulk-fuel deposition) for Jet A+MP than for the FAME-contaminated fuel. Again, this is consistent with findings in prior ARSFSS programs involving FAME contamination. In Figure 30, there appears to be no difference in the appearance of deposition for either of the fuels. This leads to the conclusion that there is no negative impact of FAME for this particular fuel.

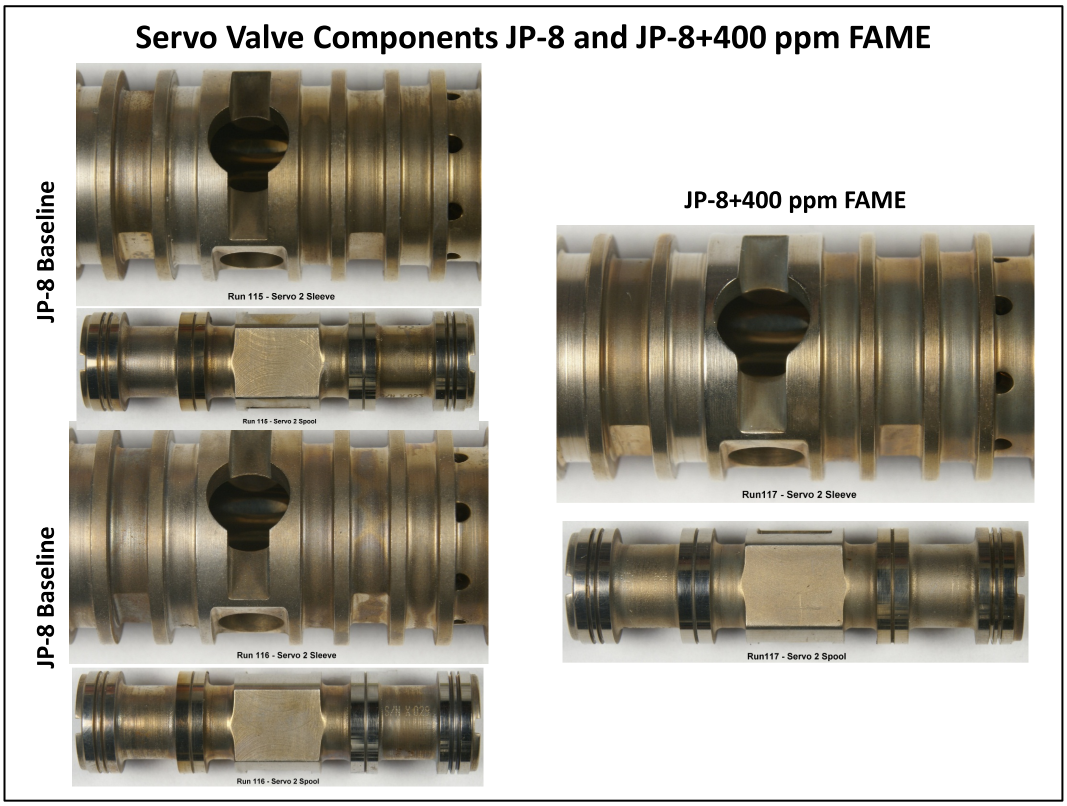

Figure 27 - Visible Deposition in the SV Components

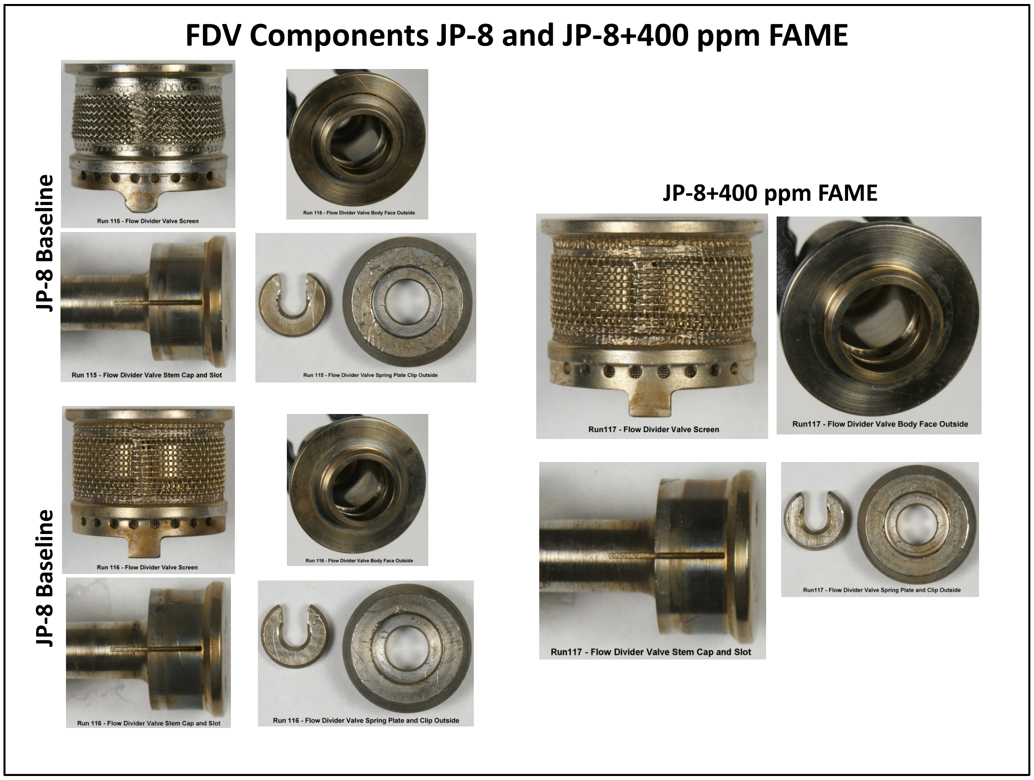

Figure 28 - Visible Deposition in FDV Components

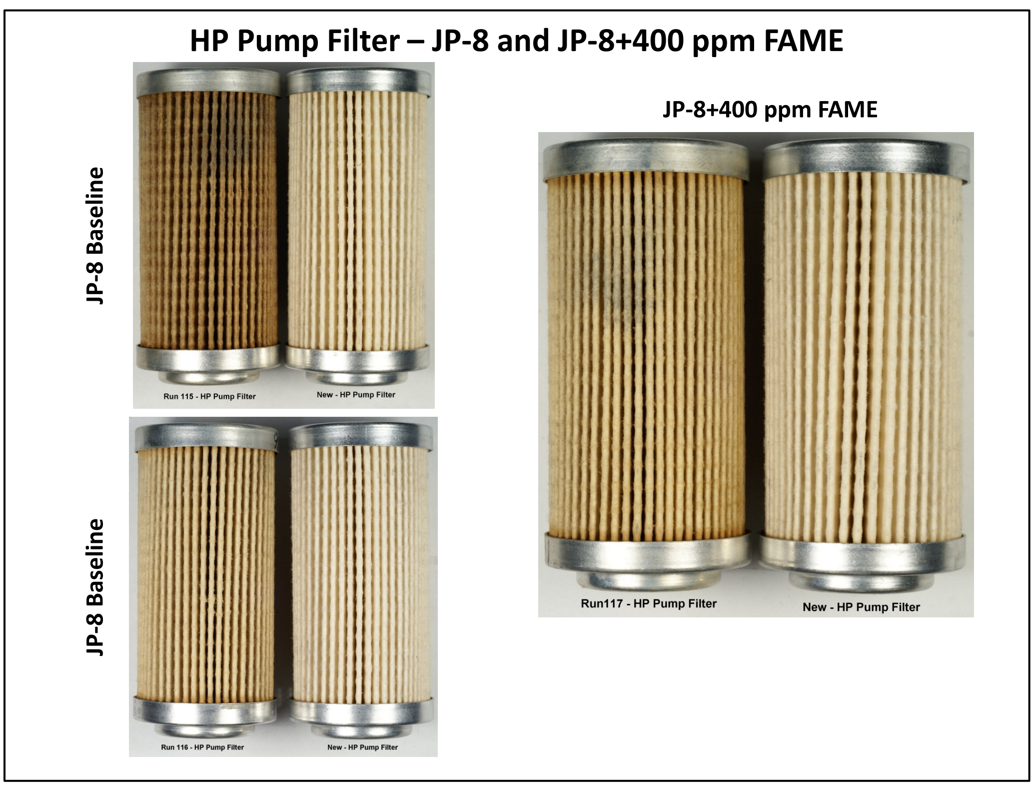

Figure 29 - Deposition in the HP Pump Filter

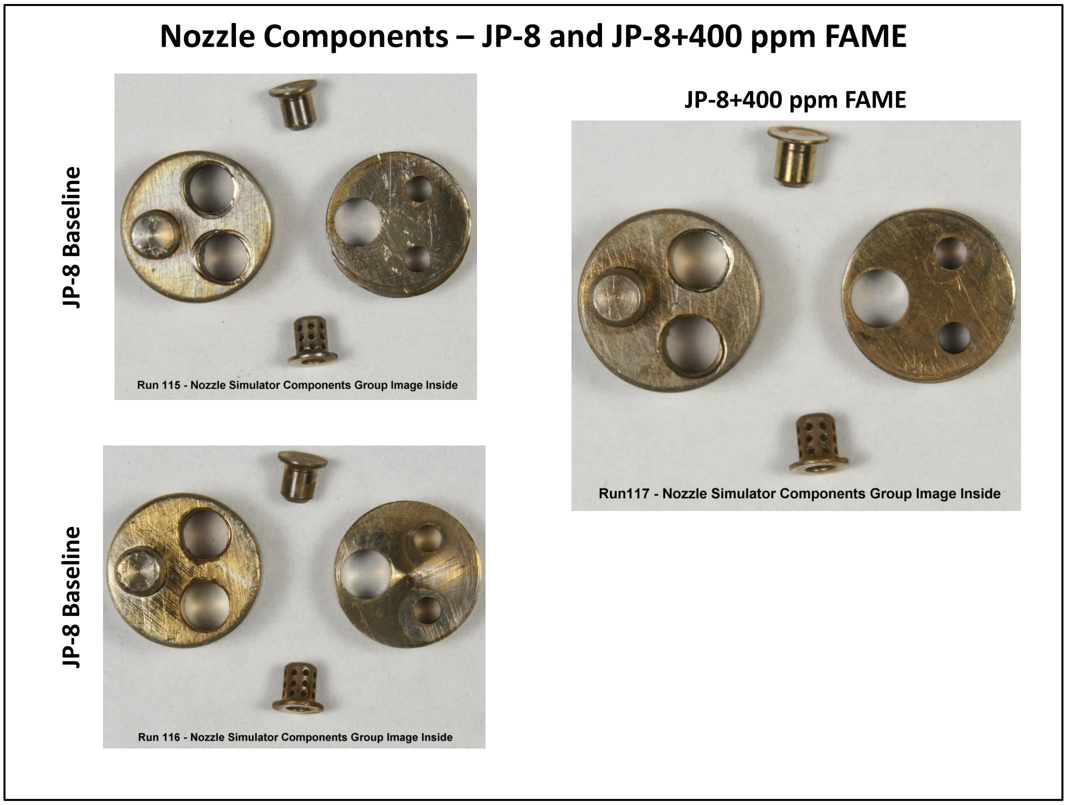

Figure 30 - Visible Deposition in Nozzle Screen Components

5.2.3 ***Evaluation of FAME in a JP-5***

5.2.3.1 FCOC and BFA Deposition

Figures 31 through 33 show the temperature history in the BFA for Runs 118 through 120. In Run 118 (Figure 31), the BFA WWT began to drift downward about half- way through the Run. This was caused by a failing RF heater being unable to maintain a fixed heat output. Adjustments were made to the heater to bring power output back to where it should be. This can be seen in the plot as a jump up in the WWT values. However, within hours the heater began to fail again. At the very end of the test, adjustments were made to bring power output back up. Taking all of this into account, it appears that there was just a minor WWT rise in the Run although it cannot be certain what the exact ramifications of the heater problems were. This brings uncertainty to the results of this Run.

Figure 32 shows BFA WWT for Run 119 (a baseline JP-5 repeat run). At about 80% of the way through the Run, the BFA RF heater began to fail again, this time with slightly more dramatic temperature drop-off. The heater was adjusted and the Run completed. While this again leads to some skepticism regarding the results of the Run, if can be concluded with at least some certainty that, at least for the 80 percent of the test where the RF heater was functioning properly, BFA WWT rise was small – in the vicinity of about 2 °F . It is possible that had the RF heater not malfunctioned, the temperature rise might have been slightly higher, but probably not significantly.

Figure 33 shows the BFA WWT plot for the final run of this program, Run 120 – the FAME-contamination Run. The fuel for this run was the baseline JP-5 with 400 ppm FAME. The results of this Run are totally inconclusive, again due to the mid-Run failure of the BFA RF heater to maintain a fixed power output. By just one-fourth of the way into the Run, the RF heater began losing power at a rapid

rate. At a little over half-way through the Run adjustments were again made to the RF heater, the heater never fully recovered the full power output required to achieve target Run temperature thereby invalidating this Run.

Figures 34 and 35 show Effective Carbon Deposition for the FCOC and BFA respectively. The deposition for all fuels, with or without FAME contamination, indicate no detrimental impact of FAME for carbon deposition. HOWEVER, one must consider that in Runs 118 and 120 the heater malfunction may have invalidated the data. Therefore, assessing the temperature and deposition data from these three Runs, it can be concluded that the presence of FAME in the JP-5 PROBABLY had no detrimental effect on the fuel thermal stability but the malfunctions in the RF heater preclude a definitive conclusion.

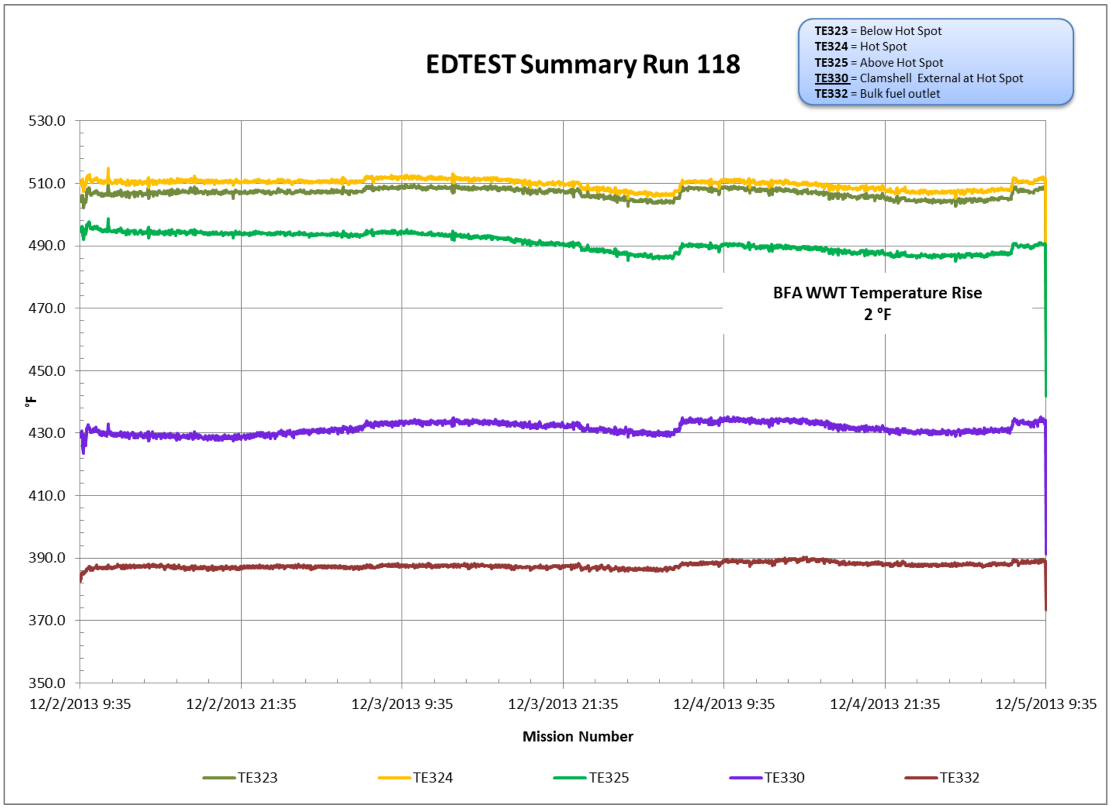

Figure 31 - BFA WWT Rise, Run 118

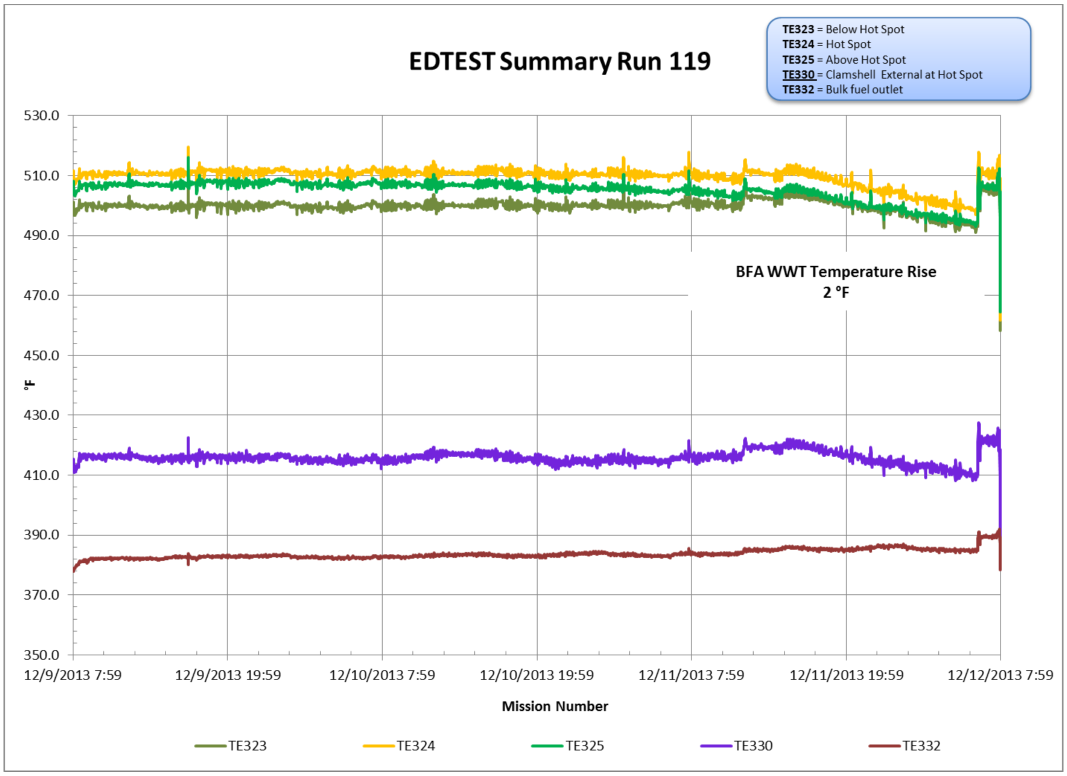

Figure 32 - BFA WWT Rise, Run 119

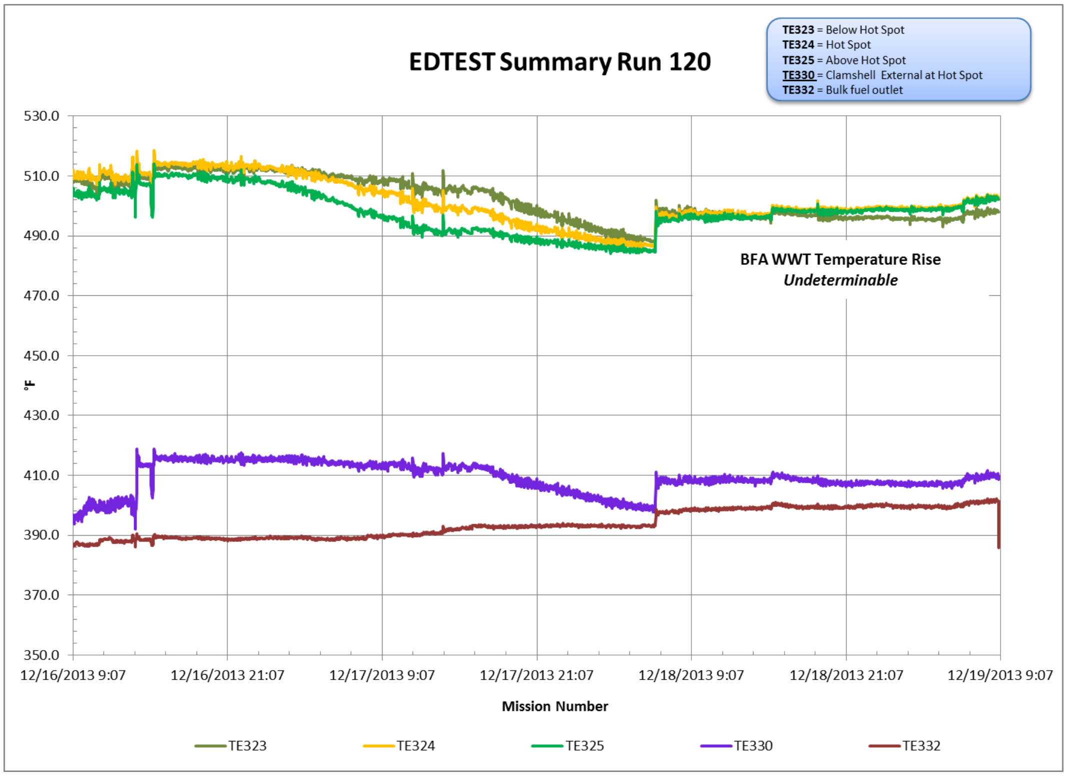

Figure 33 - BFA WWT Rise, Run 120

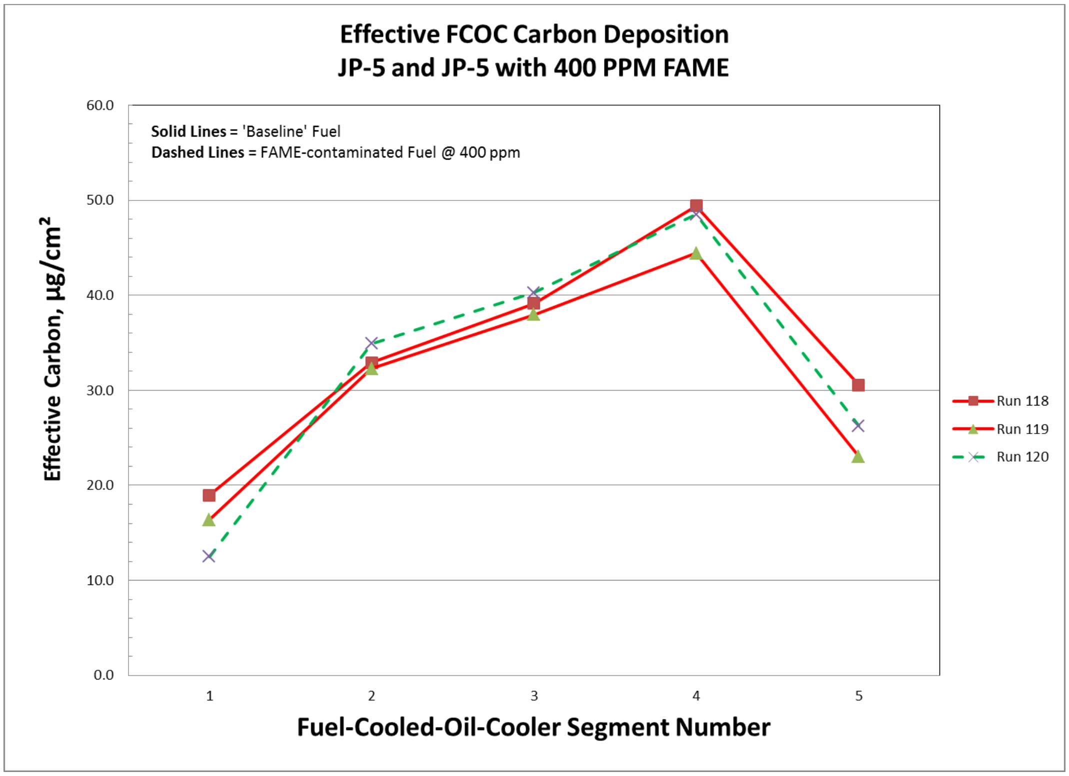

Figure 34 - FCOC Carbon Deposition, Runs 118 - 120

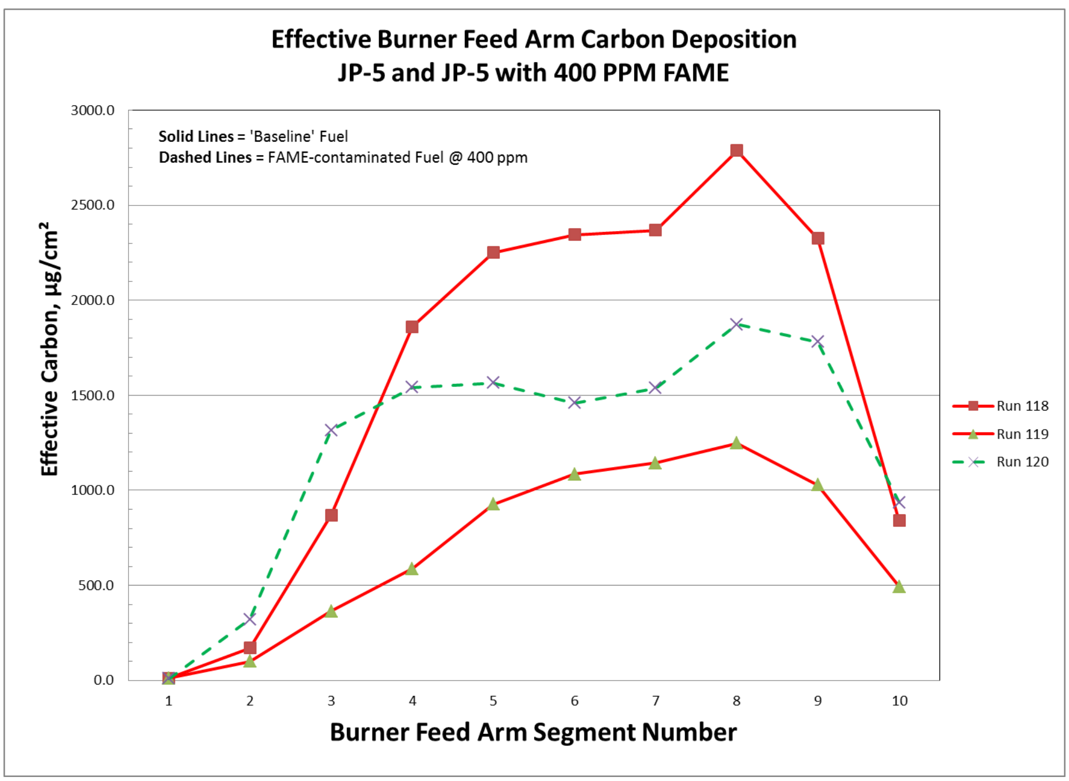

Figure 35 - BFA Deposition, Runs 118 - 120

5.2.3.2 Servo Valve (SV) and Flow Divider Valve (FDV) Hysteresis

Figures 36 and 37show the hysteresis in the Servo Valve subjected to non-FAME-contaminated JP-5. There is little to no post-test spread for the flow measurement when compared to the pre-test spread in Runs 118 and 119. Only slightly more hysteresis is present in Run 118 than in 119. As in some prior tests, there is increased hysteresis is a the end of valve travel so it is more likely a hysteresis introduced by the valve itself and not the fuel since hysteresis pre- and post-test in the middle operating range of the valve is non-existent. Figure 38 shows the hysteresis measured when the Servo Valve is subjected to that same JP-5 fuel with FAME contamination. As to Runs 118 and 119, there does not appear to be any hysteresis in the extreme ends of valve travel but it can be noted that there has been a general shift in the Post-test plot compared to the Pre-test plot. This indicates that the valve has ‘worn in’ a little thereby shifting its inherent flow characteristics slightly. This is not a function of fuel deposition. It can therefore be concluded that FAME had no detrimental impact on the JP-5 with regard to SV hysteresis.

Figures 39 and 40 show the hysteresis in the FDV when subjected to non-FAME-contaminated JP-8. In these plots, there is no apparent hysteresis pre- versus post-test in either baseline Run. However, Figure 41 shows FDV hysteresis when using FAME-contaminated JP-5 and in this case, there is a small apparent change in FDV hysteresis leading to the conclusion that there may be some detrimental impact of FAME for this fuel. However, the fact that the RF heater malfunctioned during this run considerably negates drawing any firm conclusion based on this data

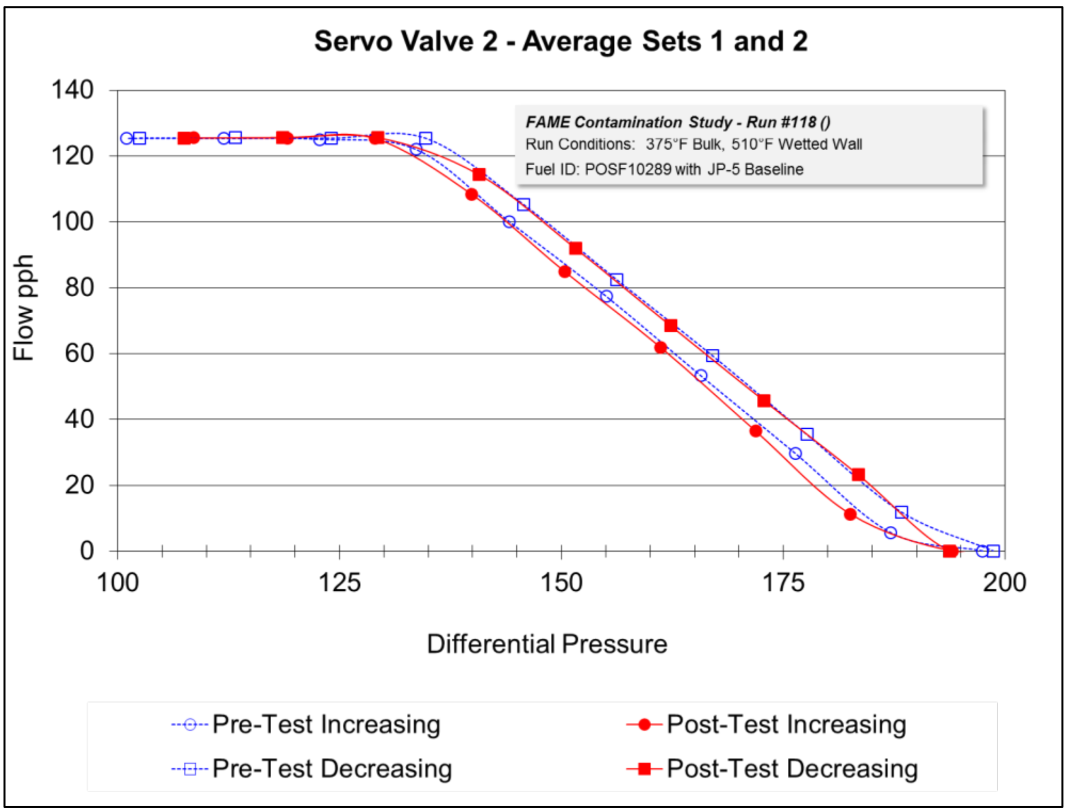

Figure 36 - Servo Valve Hysteresis, Run 118

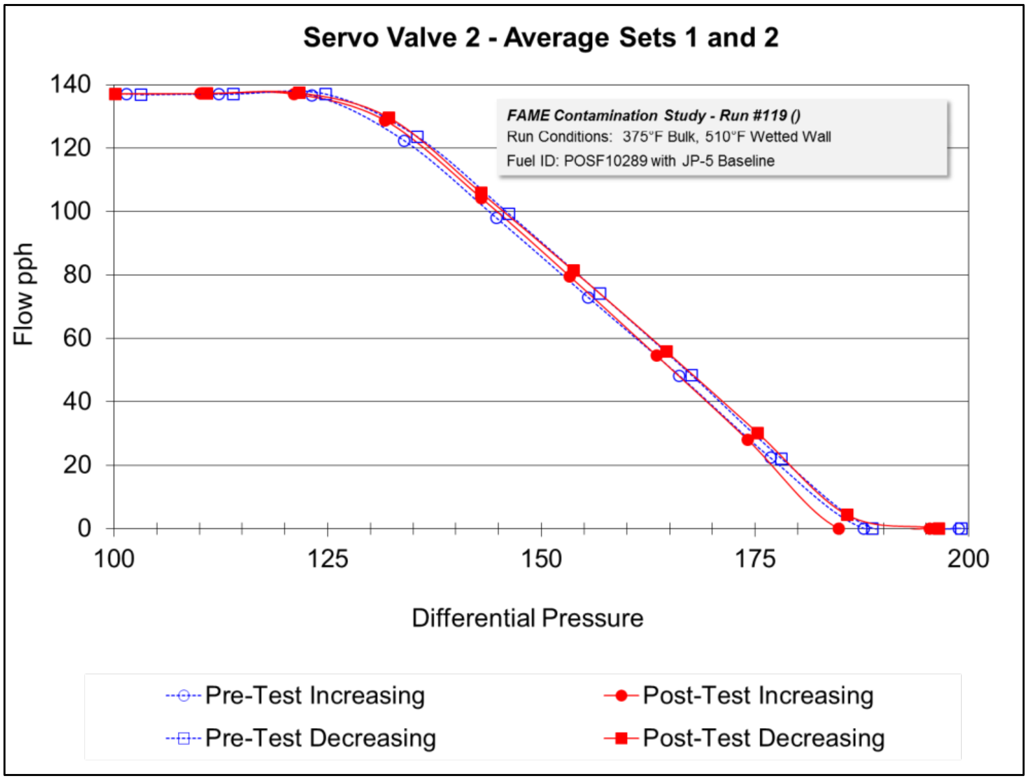

Figure 37 - Servo Valve Hysteresis, Run 119

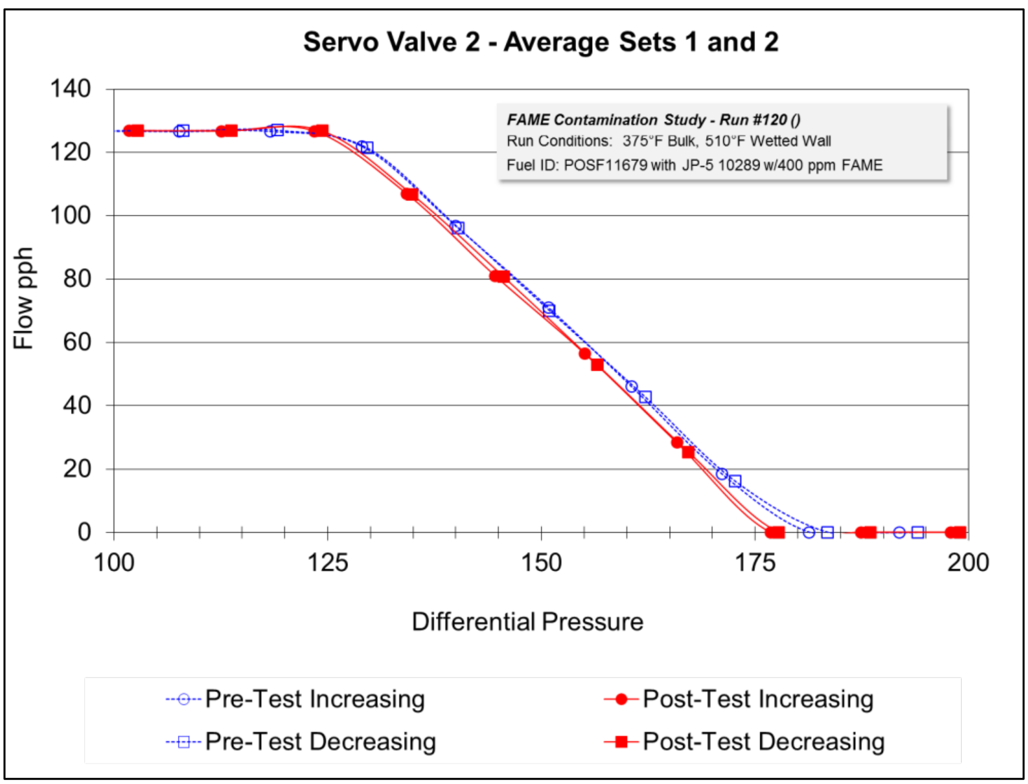

Figure 38 - Servo Valve Hysteresis, Run 120

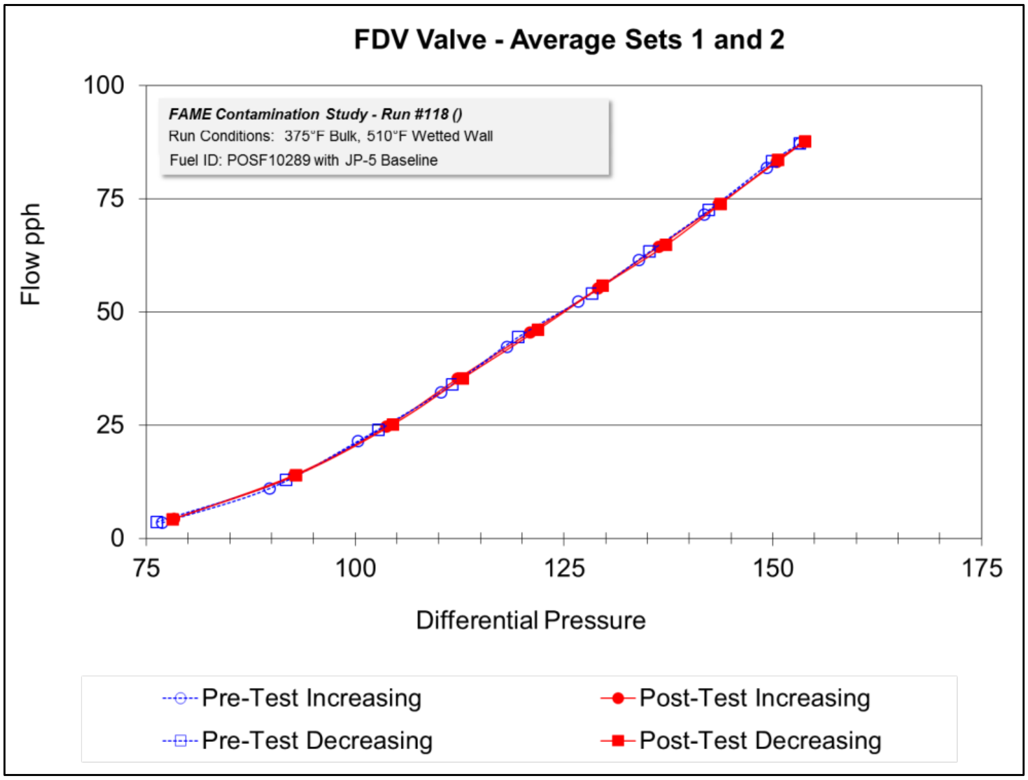

Figure 39 - FDV Hysteresis, Run 118

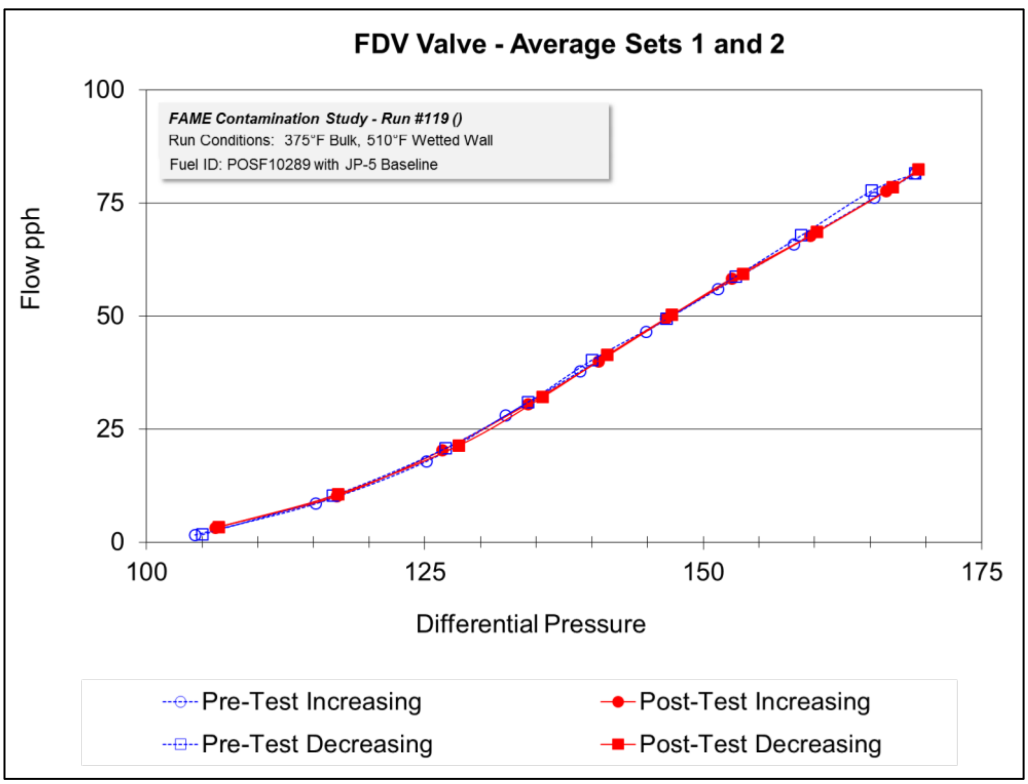

Figure 40 - RDV Hysteresis, Run 119

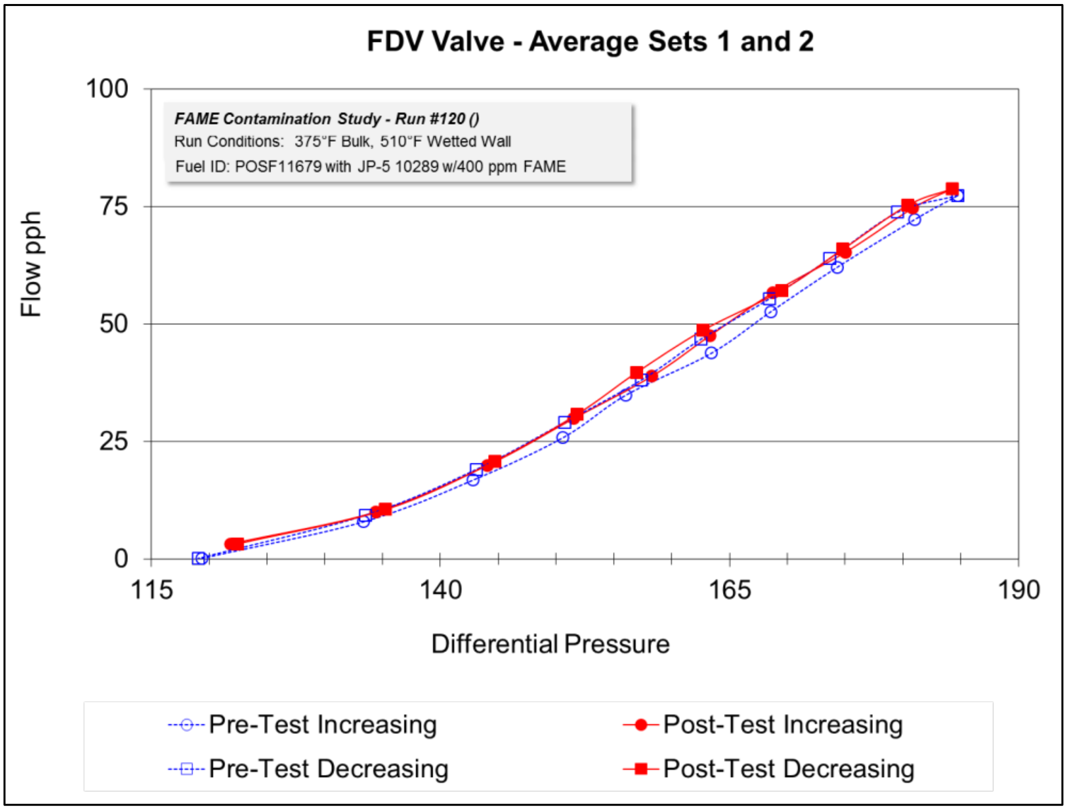

Figure 41 - FDV Hysteresis, Run 120

5.2.3.3 Visible Deposition in Fuel-Wetted Components

Figures 42 through 45 present images of fuel-wetted components used in the ARSFSS to provide a visual comparison of deposition. Figure 42 shows deposition appearance in the SV, Figure 43 shows deposition appearance in the FDV components. Figure 44 shows the appearance of the filter at the HP Pump inlet and Figure 45 shows deposition appearance in the Nozzle Simulator (NS) device. The NS is similar to the Torque Motor Screen in the Aviation Fuel Thermal Stability Test Unit (AFTSTU) located at the University of Sheffield in the UK.

In Figures 42 and 43, there appears to be lighter deposition in the SV and FDV components with the Jet A+MP and JP-8 fuel. There appears to be little or no difference in deposition in these same components when using FAME-contaminated fuel. By contrast, Figure 44 shows the HP Pump filter to be significantly darker in appearance than the baseline Run filters. The HP Pump filter is situated at the outlet of the HP Pump and the HP Pump is upstream of both the FCOC and BFA. Fuel is recirculated from downstream of the FCOC, through the SV and back to the fuel tanks on the ARSFSS. Hence, the HP Pump filter sees recirculated fuel that has been exposed to the temperatures in the FCOC **but not** to the temperatures in the BFA (See Figure 46, the ARSFSS Flow Schematic). Therefore, this HP Pump filter may provide the only reliable evidence of any impact of FAME on JP-5. If such is the case, it might be concluded that FAME had, at least for this fuel, an apparent negative impact on the fuel. However, considering the FCOC deposition plot (Figure 34) did not show a negative impact, a firm conclusion still eludes. It may be that this data may be indicating that the presence of FAME in JP-5 may have an impact on bulk fuel deposition but not on heated wetted-wall deposition.

Figure 45 shows deposition on the Nozzle Screen components. Here also, there appears to be slightly greater deposition in this device for the FAME-contaminated JP-5 than the baseline JP-5. However, this does not seem to be enough to merit a conclusion that FAME is detrimental to JP-5.

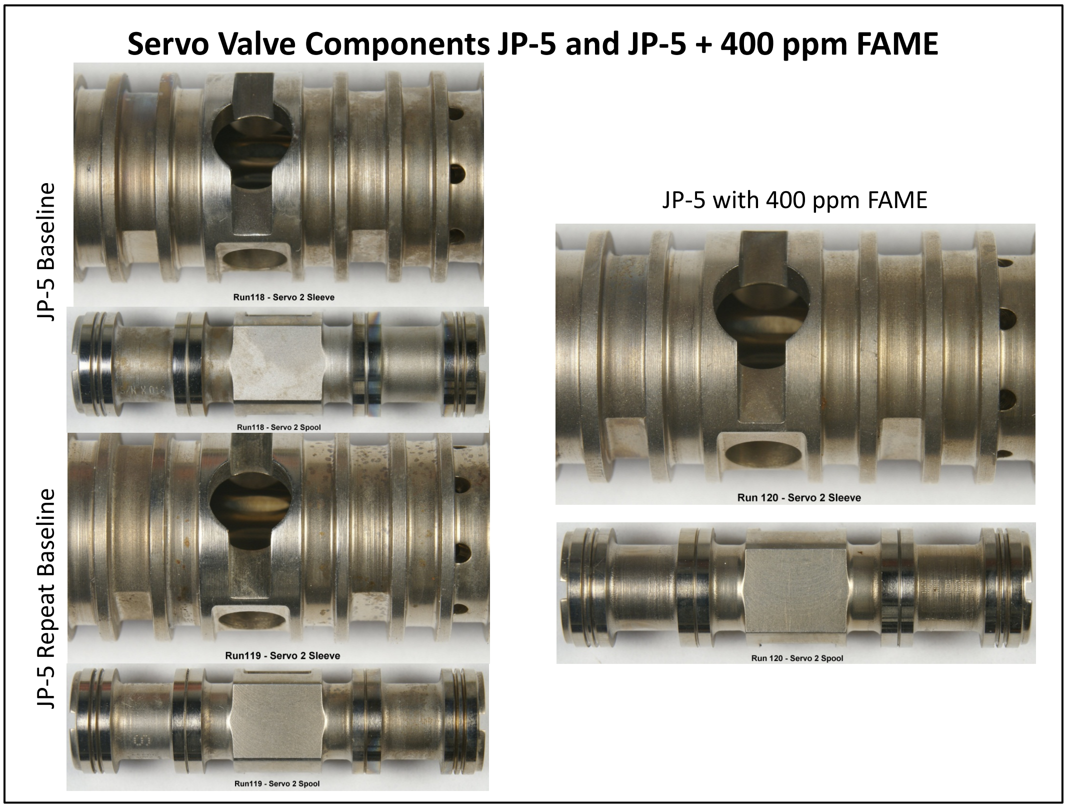

Figure 42 - Visible Deposition, SV Components, JP5 and JP-5 With FAME Contamination

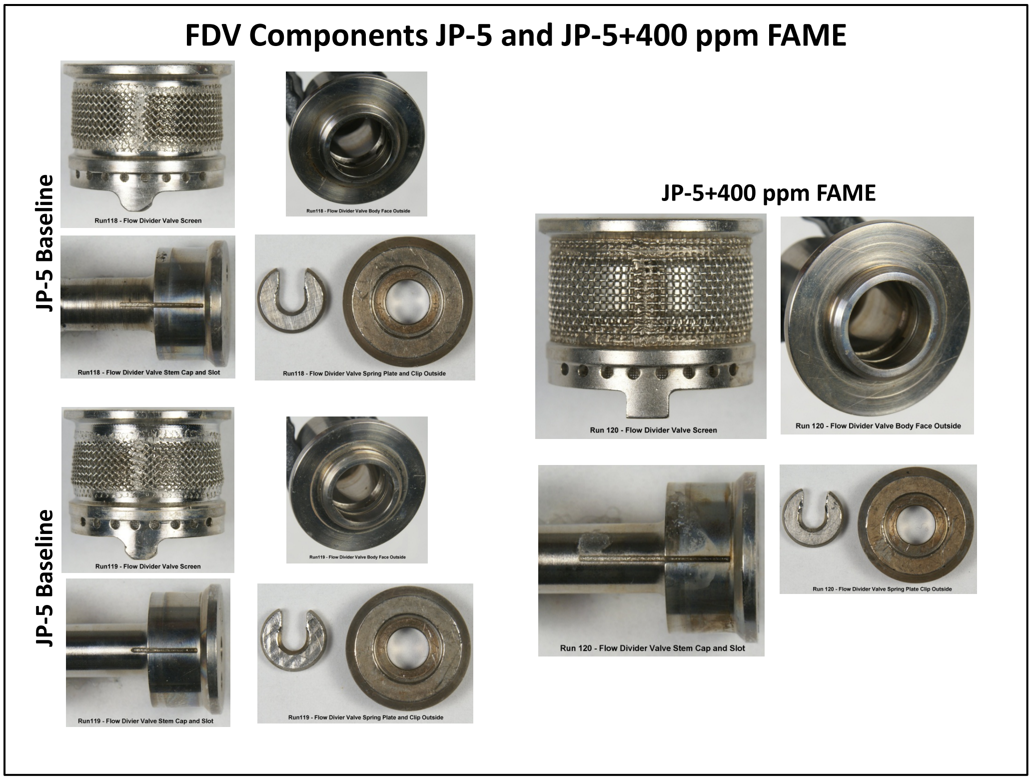

Figure 43 - Visible Deposition, FDV Components - JP-5 and JP-5 With FAME Contamination

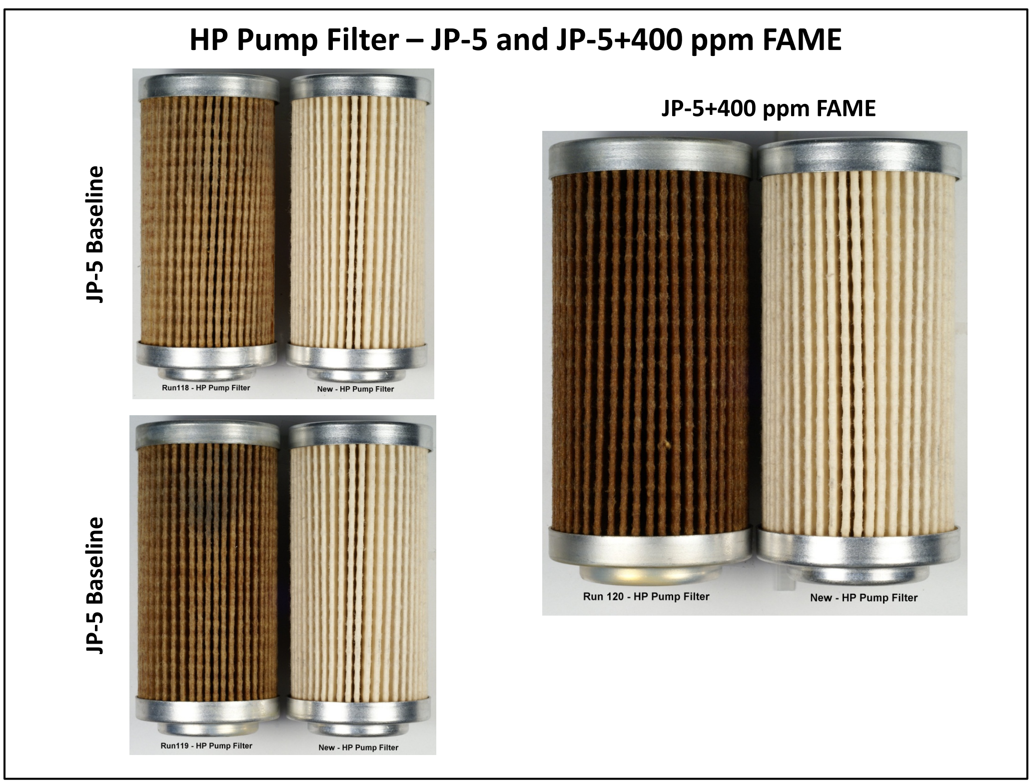

Figure 44 - HP Pump Filter, JP-5 and JP-5 With FAME Contamination

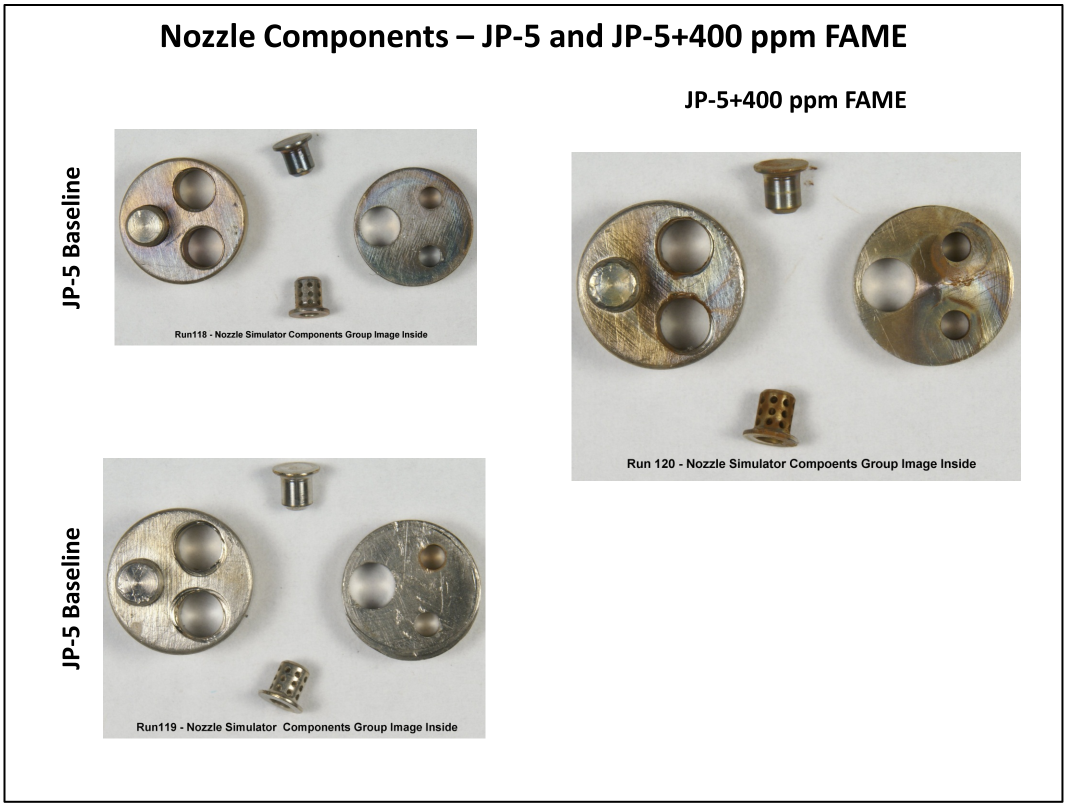

Figure 45 - Visual Deposititition NS Components, JP-5 and JP-5 With FAME Contamination

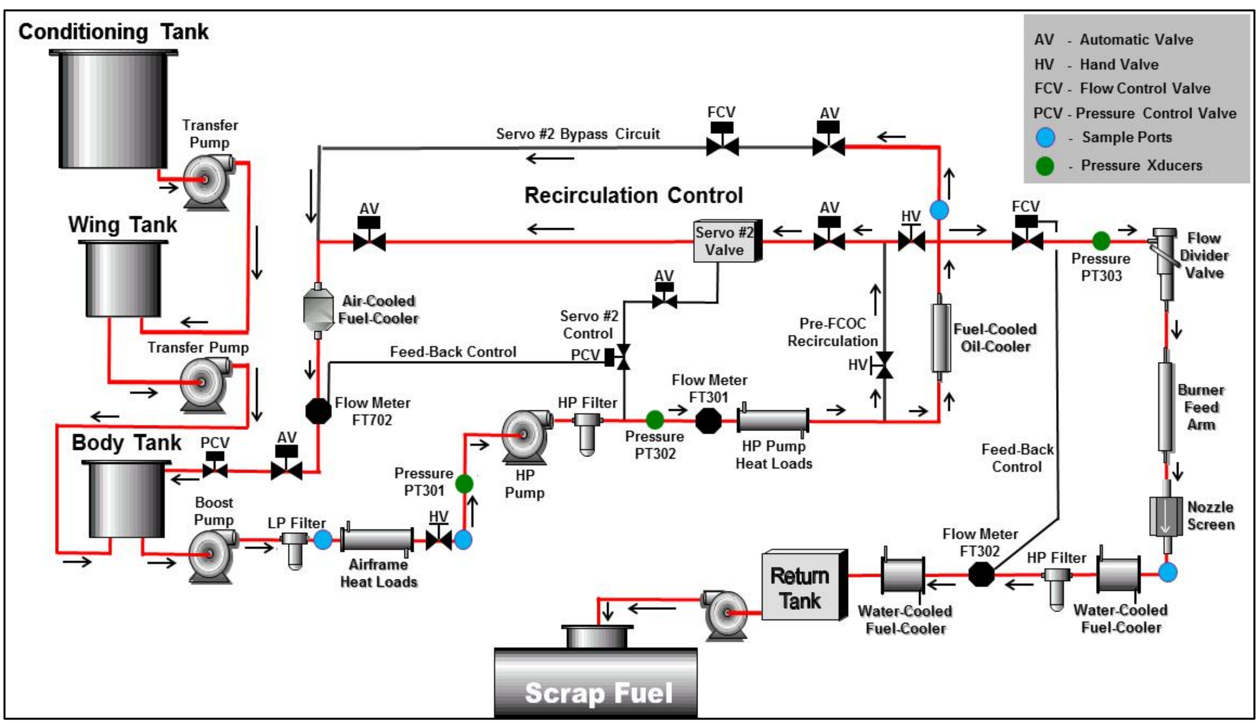

Figure 46 - ARSFSS Flow Schematic

5.3 Quartz Crystal Microbalance (QCM) Analyses

Thermal stability characteristics of fuel samples for this program were assessed using a QCM apparatus. The experiment was conducted by placing 60 mL of sample into a batch reactor. The sample was air saturated under room conditions, then closed and heated to 140°C. Measurements of headspace oxygen, temperature, pressure, and mass accumulation were recorded, while the sample was reacted isothermally for 15 hours. The objective was to investigate the oxidation and mass deposition characteristics of the experimental samples under typical QCM conditions in an effort to identify any differences in thermal stability behavior with the addition of FAME impurity.

Figure 47 shows the headspace oxygen and mass accumulation profiles of a Jet A fuel (F10325), the Jet A fuel with MIL Spec Additives (i.e., FSII, CI/LI, and SDA) and with the MIL Spec Additives and 400 mg/kg of FAME (F11039). All three samples exhibit similar, slow oxidation rates and give medium-low levels of deposit (≤3 μg/cm^2). **There are no significant differences in the overall thermal stability character of these three fuel samples.**

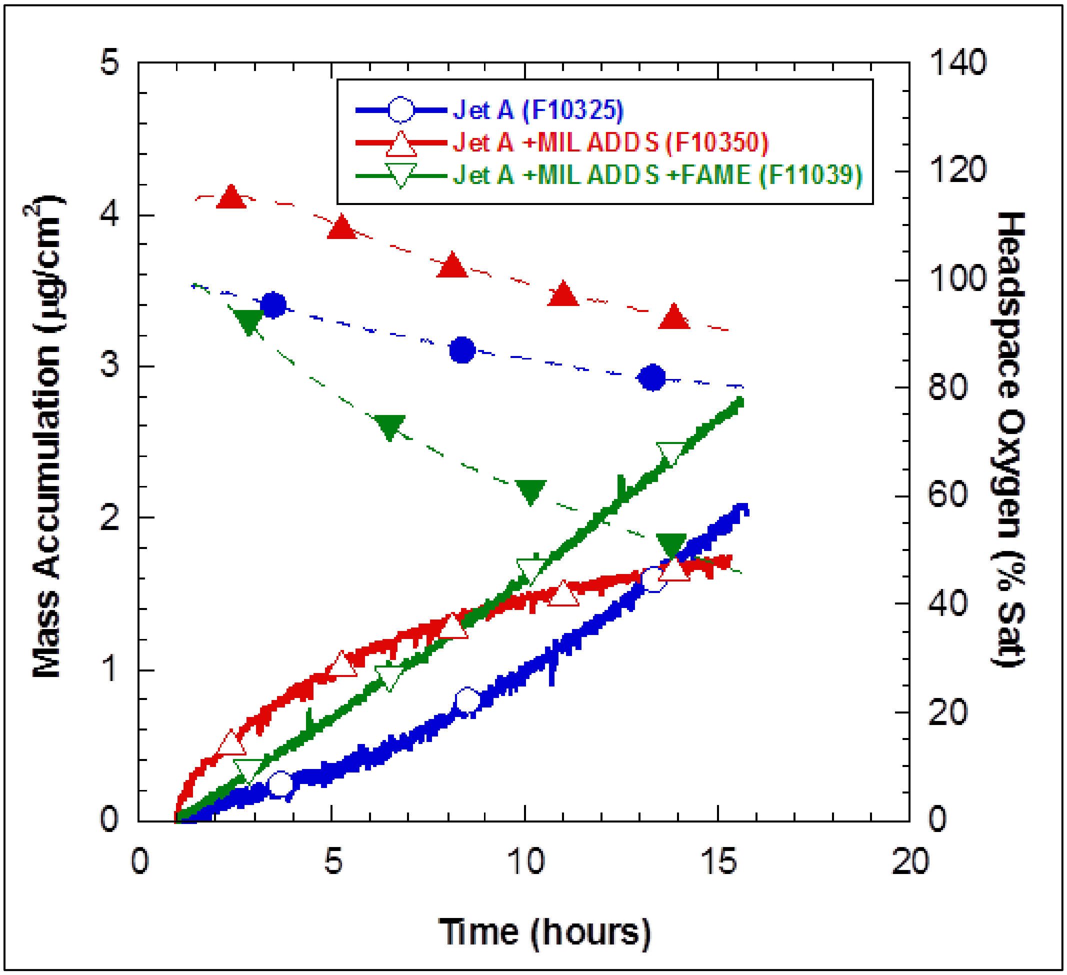

Figure 47 - QCM Deposits and Relative Headspace Oxygen - Jet A+MP and Jet A+MP+FAME

Figure 48 shows the results of a JP-5 fuel with and without 400 mg/kg of FAME, F11679 and F10289, respectively. The oxidation profiles for the two samples are almost identical, and the deposition profiles follow similar trends. However, the absolute deposition amounts after about 7 hours of thermal stressing appear different. Nevertheless, **both fuels deposit within a typical range for specification JP-8 fuels** of

≤6 μg/cm². More testing would be required to determine if the differences in deposition amounts are significant under these conditions.

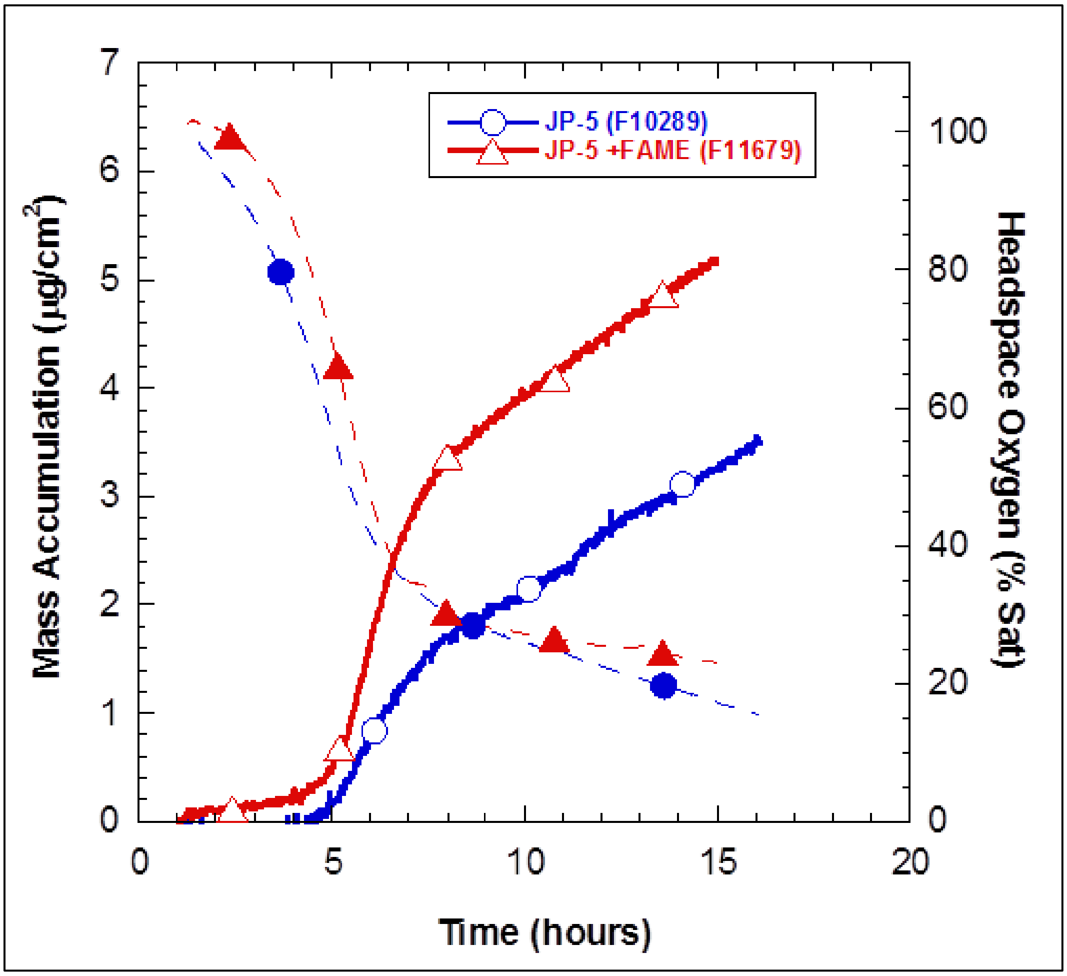

Figure 48 - QCM Deposits and Relative Headspace Oxygen - JP-5 and JP-5 with FAME

Figure 49 shows the headspace oxygen and mass accumulation profiles of a JP-8 jet fuel with and without 400 mg/kg of FAME, F10264 and F11585, respectively. The samples exhibit similar, slow oxidation rates and give low levels of deposit (~2 μg/cm² or less). The FAME appears to give a slight improvement in surface deposits; however, more experimentation would be required to determine if this difference is significant. The overall thermal stability characteristics of these two fuel samples are similar.

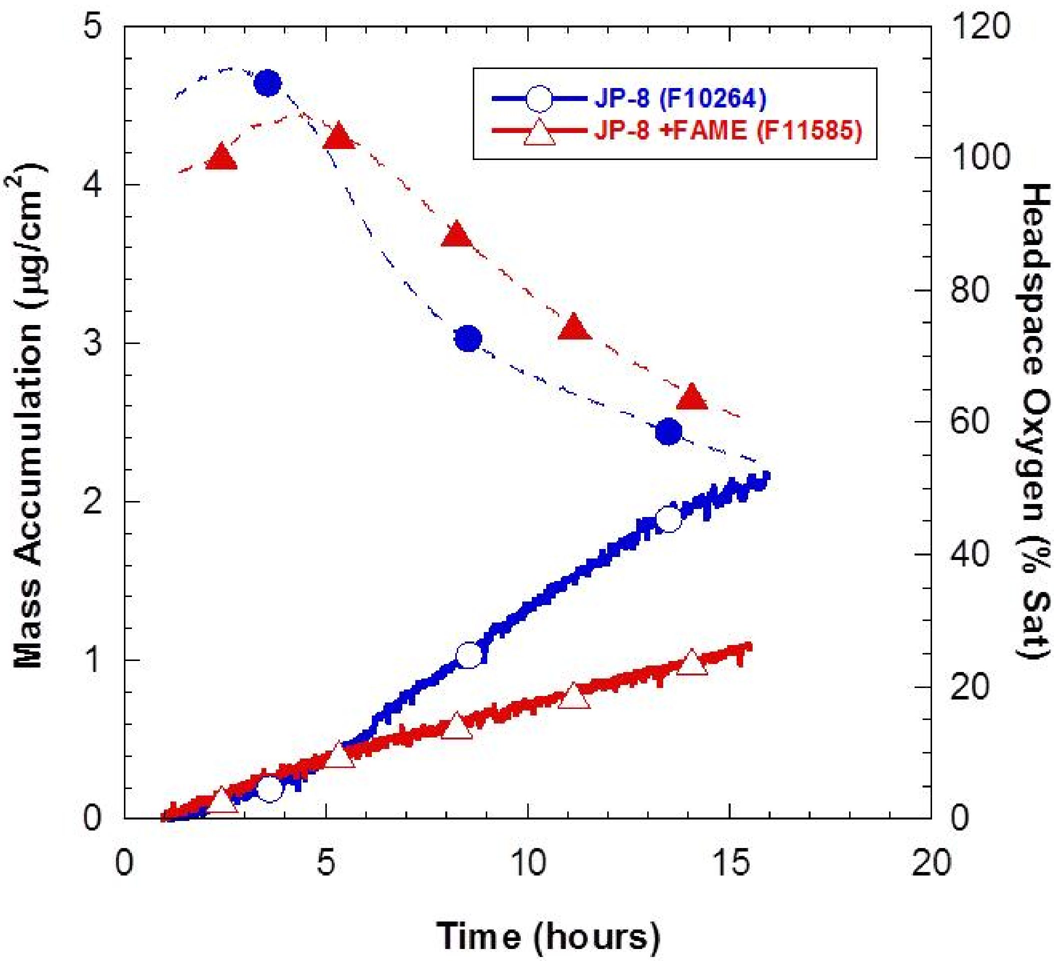

Figure 49 - QCM Deposits and Relative Headspace Oxygen - JP-8 and JP-8 with FAME.

6.0 Conclusions and Recommendations

A series of ARSFSS Runs evaluating the impact of FAME contamination on the thermal stability of a Jet A additized with a military package of additives, a JP-8 and a JP-5 were accomplished. BFA wetted-wall temperature change profiles were obtained and carbon deposition was measured. Photographs were taken of deposition on fuel-wetted components.

In all cases, with the exception of JP-5, data shows no significant difference in deposition from a baseline fuel and a FAME-contaminated fuel. For these fuels, it can be concluded that FAME contamination of Jet A used as a replacement for JP-8 and JP-8 itself will not likely adversely impact weapons systems using these fuels, regardless if the exposure to the contaminated fuel is periodic or long-term.

For the JP-5, there is conflicting evidence regarding the impact of FAME on this fuel, primarily due to the malfunction of test hardware. However, even considering the likelihood that the test hardware may have had an impact on the test data, it can be reasonably concluded from an examination of the data that if there is a negative impact of FAME contamination on JP-5, the impact is minimal. Hence one would not expect any adverse impact on weapons systems using FAME-contaminated JP-5 as long as that exposure to the contaminated JP-5 was minimal or periodic.

These fuels were also evaluated in the QCM. Results of these analyses show that for JP-8 and Jet A plus the mil-pack additives, FAME has no detrimental impact on the fuel. With JP-5, QCM showed slightly increased deposition with the JP-5 containing FAME but the deposition experienced was within the normal experience of JP-8s.

It is therefore generally concluded that FAME has no significant impact on either Jet A with the military package of additives or JP-8 or JP-5, although the data is less conclusive for the JP-5 than for the Jet A with the military package of additives and the JP-8.

APPENDIX

Fuel Specification Test Sheets

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA43403001 | Date Received:04/09/13 0709 hrs* | Date Sampled: **
Cust Sample No:10264 | Date Reported:04/16/13 1411 hrs* | Protocol:FU-AVI-0019
JON: GENERAL FUND

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Reason for Submission: AFRL Research
Product: Aviation Turbine Fuel, Kerosene
Specification: MIL-DTL-83133H w/Amd 1 Grade:JP-8

Qty Submitted: 2 gal
Batch/Lot/Origin: JP-8

Method	Test	Min	Max	Result	Fail
ASTM D 2622 - 10	Sulfur (% mass)		0.30	0.004	
ASTM D 7171 - 05	Hydrogen Content by NMR (% mass)			14.4	
ASTM D 3242 - 11	Total Acid Number (mg KOH/g)		0.015	0.008	
ASTM D 1319 - 10	Aromatics (% vol)		25.0	11.2	
ASTM D 3227 - 04a	Mercaptan Sulfur (% mass)		0.002	0.000	
ASTM D 86 - 12	Distillation				
	Initial Boiling Point (°C)			145	
	10% Recovered (°C)		205	164	
	20% Recovered (°C)			171	
	50% Recovered (°C)			189	
	90% Recovered (°C)			234	
	End Point (°C)		300	256	
	Residue (% vol)		1.5	1.2	
	Loss (% vol)		1.5	0.5	
ASTM D 93 - 12	Flash Point (°C)	38		42	
ASTM D 4052 - 11	Density @ 15°C (kg/L)	0.775	0.840	0.780	
ASTM D 5972 - 05e1	Freezing Point (°C)		-47	-51	
ASTM D 1322 - 12e1	Smoke Point (mm)	25.0		28.5	
ASTM D 130 - 12	Copper Strip Corrosion (2 h @ 100°C)	1 (Max)		1a	
ASTM D 3241 - 11a	Thermal Stability @ 260°C				
	Tube Deposit Rating, Visual	<3 (Max)		1	
	Change in Pressure (mmHg)		25	0	
ASTM D 381 - 12	Existent Gum (mg/100 mL)		7.0	<1	
ASTM D 5452 - 12	Particulate Matter (mg/L)		1.0	0.4	
MIL-DTL-83133H w/Amd 1	Filtration Time (min)		15	4	
ASTM D 1094 - 07	Water Reaction Interface Rating	1b (Max)		1	
ASTM D 3948 - 11	WSIM	70		83	
ASTM D 5006 - 11	FSII (% vol)	Report Only		0.11	
ASTM D 2624 - 09	Conductivity (pS/m)	150	600	40	X
ASTM D 5001 - 10	Lubricity Test (BOCLE) Wear Scar (mm)	Report Only		0.52	
ASTM D 4809 - 09ae1	Net Heat of Combustion (MJ/kg)	42.8		43.1	
ASTM D 1319 - 10	Olefins (% vol)	Report Only		0.4	
ASTM D 445 - 12	Viscosity @ -20°C (mm^2/s)		8.0	3.5	

Dispositions:
For information purposes only.

* Date reflects Eastern Standard Time(EST) | Report Generated: 04/16/13 14:11*
** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA43403001	Date Received:04/09/13 0709 hrs*	Date Sampled: **
Cust Sample No:10264	Date Reported:04/16/13 1411 hrs*	Protocol:FU-AVI-0019
JON: GENERAL FUND		

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Approved By	**Date**
Miguel Acevedo, Chief \\SIGNED\\	04/16/2013*

This report was electronically delivered to:
benet.curtis@wpafb.af.mil, donald.minus@wpafb.af.mil, emilio.alfaro@wpafb.af.mil, james.edwards@wpafb.af.mil, janet.swartz@wpafb.af.mil, jennifer.engelman@wpafb.af.mil, linda.shafer@wpafb.af.mil, miguel.acevedo@wpafb.af.mil, rhonda.cook.ctr@wpafb.af.mil

* Date reflects Eastern Standard Time(EST) | Report Generated: 04/16/13 14:11*
** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA43919001 Date Received:05/07/13 0908 hrs* Date Sampled: **
Cust Sample No:10289 Date Reported:05/16/13 1325 hrs* Protocol:FU-AVI-0094
JON: GENERAL FUND

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Reason for Submission: AFRL Research
Product: Aviation Turbine Fuel, Kerosene
Specification: MIL-DTL-5624U Grade:JP-5

Qty Submitted: 2 gal Qty Rep: 5,959 gal

Method	Test	Min	Max	Result	Fail
MIL-STD-3004C(1)	Appearance			Pass	
ASTM D 6045 - 12	Color, Saybolt	Report Only		+25	
ASTM D 3242 - 11	Total Acid Number (mg KOH/g)		0.015	0.006	
ASTM D 1319 - 10	Aromatics (% vol)		25.0	18.3	
ASTM D 3227 - 04a	Mercaptan Sulfur (% mass)		0.002	0.000	
ASTM D 4294 - 10	Total Sulfur (% mass)		0.30	0.02	
ASTM D 86 - 12	Distillation				
	Initial Boiling Point (°C)	Report Only		174	
	10% Recovered (°C)		205	192	
	20% Recovered (°C)	Report Only		199	
	50% Recovered (°C)	Report Only		218	
	90% Recovered (°C)	Report Only		244	
	End Point (°C)		300	258	
	Residue (% vol)		1.5	1.0	
	Loss (% vol)		1.5	0.8	
ASTM D 93 - 12	Flash Point (°C)	60		60	
ASTM D 4052 - 11	API Gravity @ 60°F	36.0	48.0	39.5	
ASTM D 4052 - 11	Density @ 15°C (kg/L)	0.788	0.845	0.827	
ASTM D 5972 - 05e1	Freezing Point (°C)		-46	-50	
ASTM D 445 - 12	Viscosity @ -20°C (mm^2/s)		8.5	6.5	
ASTM D 976 - 06 (2011)	Cetane Index, Calculated	Report Only		41	
ASTM D 1322 - 12e1	Smoke Point (mm)	19.0		20.0	
ASTM D 130 - 12	Copper Strip Corrosion (2 h @ 100°C)	1 (Max)		1a	
ASTM D 3241 - 11a	Thermal Stability @ 260°C				
	Change in Pressure (mmHg)		25	0	
	Tube Deposit Rating, Visual	<3 (Max)		1	
ASTM D 381 - 12	Existent Gum (mg/100 mL)		7.0	2.4	
ASTM D 5452 - 12	Particulate Matter (mg/L)		1.0	0.9	
MIL-DTL-5624U	Filtration Time (min)		15	5	
ASTM D 7224 - 12	WSIM	70		95	
ASTM D 5006 - 11	FSII (% vol)	0.06	0.15	0.00	X
ASTM D 5001 - 10	Lubricity Test (BOCLE) Wear Scar (mm)	Report Only		0.58	
ASTM D 7171 - 05	Hydrogen Content by NMR (% mass)			13.4	
ASTM D 4809 - 09ae1	Net Heat of Combustion (MJ/kg)	42.8		43.0	

Dispositions:
For information purposes only.
Coordinated with Rick Wilkes (PTOT), phone: DSN 785-8103, COM 937-255-8103.

* Date reflects Eastern Standard Time(EST) | Report Generated: 05/16/13 14:33*
** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA43919001	Date Received:05/07/13 0908 hrs*	Date Sampled: **
Cust Sample No:10289	Date Reported:05/16/13 1325 hrs*	Protocol:FU-AVI-0094
JON: GENERAL FUND		

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Approved By	**Date**
Amanda Rowton \\SIGNED\\	05/16/2013*

This report was electronically delivered to:
amanda.rowton@wpafb.af.mil, donald.minus@wpafb.af.mil, james.edwards@wpafb.af.mil, janet.swartz@wpafb.af.mil, jennifer.engelman@wpafb.af.mil, linda.shafer@wpafb.af.mil, rhonda.cook.ctr@wpafb.af.mil, richard.wilkes@wpafb.af.mil

* Date reflects Eastern Standard Time(EST) | Report Generated: 05/16/13 14:33*
** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA44568001 Date Received:06/18/13 1322 hrs* Date Sampled: **
Cust Sample No:10325 Date Reported:06/21/13 1318 hrs* Protocol:FU-AVI-0036
JON: GENERAL FUND

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Reason for Submission: AFRL Research
Product: Aviation Turbine Fuel, Kerosene
Specification: ASTM D 1655 - 13 Grade:Jet A

Qty Submitted: 1 gal
Batch/Lot/Origin: SHELL JET A

Method	Test	Min	Max	Result	Fail
MIL-STD-3004C(1)	Appearance			Pass	
ASTM D 3242 - 11	Total Acid Number (mg KOH/g)		0.10	0.006	
ASTM D 1319 - 13	Aromatics (% vol)		25	17	
ASTM D 3227 - 04a	Mercaptan Sulfur (% mass)		0.003	0.000	
ASTM D 4294 - 10	Total Sulfur (% mass)		0.30	0.04	
ASTM D 86 - 12	Distillation				
	10% Recovered (°C)		205	176	
	20% Recovered (°C)		Report Only	184	
	50% Recovered (°C)		Report Only	205	
	90% Recovered (°C)		Report Only	244	
	End Point (°C)		300	269	
	Residue (% vol)		1.5	1.2	
	Loss (% vol)		1.5	0.2	
ASTM D 56 - 05	Flash Point (°C)	38		48	
ASTM D 4052 - 11	Density @ 15°C (kg/m³)	775	840	803	
ASTM D 5972 - 05e1	Freezing Point (°C)		-40	-52	
ASTM D 445 - 12	Viscosity @ -20°C (mm²/s)		8.0	4.5	
ASTM D 1322 - 12e1	Smoke Point				
	Smoke Point (w/allowable Naphthalenes) (mm)	18		22	
ASTM D 1840 - 07	Naphthalenes (% vol)		3.0	1.5	
ASTM D 130 - 12	Copper Strip Corrosion (2 h @ 100°C)		1 (Max)	1a	
ASTM D 3241 - 13	Thermal Stability @ 260°C				
	Change in Pressure (mmHg)		25	0	
	Tube Deposit Rating, Visual		<3 (Max)	1	
ASTM D 381 - 12	Existent Gum (mg/100 mL)		7	1	
ASTM D 1094 - 07	Water Reaction Interface Rating		1b (Max)	1	
ASTM D 3948 - 11	WSIM	70		85	
ASTM D 5006 - 11	FSII (% vol)		Report Only	0.00	
ASTM D 2624 - 09	Conductivity (pS/m)	50	600	0	X
ASTM D 5001 - 10	Lubricity Test (BOCLE) Wear Scar (mm)		Report Only	0.59	
ASTM D 7171 - 05	Hydrogen Content by NMR (% mass)			13.9	
ASTM D 1319 - 13	Olefins (% vol)			0.9	
ASTM D 4809 - 13	Net Heat of Combustion (MJ/kg)			43.0	

Dispositions:
For information purposes only.

* Date reflects Eastern Standard Time(EST) | Report Generated: 06/21/13 13:19*
** Date as provided by customer

AFPET LABORATORY REPORT
AFPA/PTPLA
2430 C Street
Building 70, Area B
Wright-Patterson AFB, OH 45433-7632

Lab Report No:2013LA44568001	Date Received:06/18/13 1322 hrs*	Date Sampled: **
Cust Sample No:Not Specified	Date Reported:06/21/13 1318 hrs*	Protocol:FU-AVI-0036
JON: GENERAL FUND		

Sample Submitter:
AFRL/RZPF
1790 Loop Road N
Bldg 490
Wright-Patterson AFB, OH 45433

Approved By	**Date**
Miguel Acevedo, Chief \\SIGNED\\	06/21/2013*

This report was electronically delivered to:
donald.minus@wpafb.af.mil, james.edwards@wpafb.af.mil, janet.swartz@wpafb.af.mil, jeffrey.braun@wpafb.af.mil, jennifer.engelman@us.af.mil, john.laugle.ctr@wpafb.af.mil, linda.shafer@wpafb.af.mil, miguel.acevedo@wpafb.af.mil, rhonda.cook.ctr@wpafb.af.mil, richard.wilkes@wpafb.af.mil, thomas.bartsch.ctr@wpafb.af.mil

* Date reflects Eastern Standard Time(EST) | Report Generated: 06/21/13 13:19*
** Date as provided by customer